UNIVERSITY OF CANTERBURY

Groundwater resource management: A sustainability analysis for the Purapurani Aquifer, Bolivia

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Abstract

Groundwater is a finite resource that is an essential component of life on Earth and vital services. Due to the increase in consumption by agricultural activities and for economic purposes, exploitation of groundwater has been increasing over the last decades. This has raised international concern, leading to a promotion of sustainable management for groundwater sources. Even though efforts in sustainable groundwater management are occurring in some countries, there is currently limited understanding of groundwater occurrence and use in Bolivia.

The Bolivian government faces the challenge of developing and disseminating information about groundwater, and promoting a sustainable use of this resource in the country. Under those circumstances, this study develops a Sustainability Analysis for the sustainable management of the Purapurani Aquifer in Bolivia and provides groundwater management suggestions and recommendations based on international groundwater management experiences.

The Sustainability Analysis framework considers resilience as a key property to achieve sustainability by analysing the capacity of a system, in this case the Purapurani Aquifer, to absorb disturbance and still retain its basic function and structure. The framework considers interactions over different time scales and interactions over different spatial scales through the evaluation of adaptive cycles and nested systems. For the Purapurani Aquifer, the connections to the Basin, Region and the Aquifer itself were considered. The adaptive cycles help to describe the biophysical (environmental) and socio-economic cycles of the Aquifer, and identify processes that operate at those spatial scales.

The adaptive cycle comprises four phases: exploitation of resources, the accumulation of material resulting from resource use, the disturbance and release of material that can potentially change the system, and the reorganisation phase, which is the system response to the disturbance. The system response can be the recovery of the original system or a shift to an alternative degraded state. In order to develop this analysis, it was necessary to gather scattered information about the Purapurani Aquifer, including environmental, legal and socio-economic characteristics that are relevant for its management and that influence the sustainability of the system. The analysis also contemplated the identification of failure pathways that create vulnerability in the system, and critical variables and thresholds which represent parameters that change the state of the system. Finally, management interventions and institutional arrangements required to guarantee sustainability in the system were identified.

Information gathered regarding hydrogeological characteristics were found to be interrelated and complementary to each other; although some issues in regard to methodology and gaps in information were also identified. These issues were based mainly on a lack of updated information for the formulation of results: the data used do not correctly reflect the current situation of the Aquifer.

Regarding legal and socio-economic information, it was possible to identify that this type of information is managed separately from hydrogeological reports, failing to provide a complete overview and understanding of the groundwater system. Under those circumstances, it is essential to promote a new integrated view of management of water resources in Bolivia, where we recognise the importance and influence of legal and socio-economic information in the maintenance and management of a natural resource.

The information collected through interviews helped in understanding and considering current management perceptions and approaches with regard to the Purapurani Aquifer. This process provided new knowledge significant to this study, introducing stakeholders and the community views and suggestions in the recommendations for management interventions. Main outcomes from this process were the necessity to develop communication spaces with the community and stakeholders, and promote educational activities and capacity building for the purpose of introducing the concept of sustainable management of groundwater.

As a result of the development of the cycles for each scale and the nested system, it became clear that the current exploitation and contamination in the Purapurani Aquifer has led to a degradation of the cycle, which also affects other scales. It was also recognised that these effects were mainly a consequence of activities developed at Basin and Regional scales. Such is the case of the contamination of surface water due to lack of sewage treatment, and inefficient management of wastewater in the Region of La Paz, which are the main sources for recharge in the Aquifer. Socio-economic activities such as an increase in water demand, unsustainable use of groundwater, and a lack of appropriate management and regulation, influence the degradation of the system leading it to an unsustainable stage.

There are two main failure pathways that cause the system to shift to a degraded state: *local environmental degradation* through water contamination, and *local natural resource depletion* through the identification of an overexploitation of the Aquifer. Other failure pathways identified were climate change, and collapse of trade networks, at the Regional Scale; and water availability, impact of water use, natural disasters, and institutional arrangements at Basin Scale.

As for the identification of critical variables and thresholds, it was easy to corroborate what was concluded in early stages: the system lacks a regulation mechanism for groundwater management. Current enforced legislation only addresses water quality parameters and discharge limits, but there is no evidence of approaches to regulate exploitation rates of either surface or groundwater sources. Despite current government approaches ensuring quality of life to their inhabitants being nationally promoted, they lack sustainability concepts. It was found that current legislation and regulation is focused on covering current water demand without considering future demands.

Based on all the observations, there are management interventions needed to address these failure pathways and critical variables, with the intention of implementing the concept of sustainability in the Purapurani Aquifer. The main management interventions can be summarised in four groups: (a) groundwater availability and protection; (b) social participation, capacity building and education; (c) institutional arrangements and legal instruments; (d) developing information and monitoring mechanisms.

The assessment provides a new perspective on the information related to current groundwater resources management in the country. Management suggestions and policy options suggested above aim to guide Bolivian decision makers to promote a sustainable management of groundwater resources in the country..

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Abbreviations

AACD	Regional Competent Environmental Authority
AACN	National Competent Environmental Authority
AAPS	Authority of Supervision and Social Control of Water and Sanitation
AAS	Environmental and Social Analysis
AJAM	Mining Administrative Judicial Authority
APA	Plurinational Water Authority
BID	Inter-American Development Bank
BPS	Biophysical system
CAF	Development Bank of Latin America
CAPyS	Committee of Drinking Water and Sanitation
CIS	Common Implementation Strategy
CNI	Chamber of Industry
COD	Chemical Oxygen Demand
CODAGUA	Regional Water Councils
COPAGUA	Plurinational Water Council
CPE	Political Constitution of the State
CSO	Competent Sector Organisations
CWMS	Canterbury Water Management Strategy
ECAN	Environment Canterbury
EIA	Environmental Evaluations
EMAGUA	Environmental and Water Enforcement Entity
EMAPAV	Municipal Water and Sanitation Company of Viacha
EPSA	Water and Sewerage Services Company
EPSAS	Social Public Company for Potable Water and Sanitation of La Paz - El Alto
EU	European Union
FEFLOW	Finite Element subsurface flow system
FEJUVE	Federation of Neighbourhood Boards
FERMIPE	Federation of Micro and Small Entrepreneurs
FUOPMEA	El Alto Federation of Women's Organisations
GAB	Great Artesian Basin
GADLP	Autonomous Government of the Region of La Paz
GAMEA	Autonomous Municipal Government of El Alto
GAMLP	Autonomous Municipal Government of La Paz
GEOBOL	Geological Service of Bolivia
GIS	Geographical Information System
HRtW	Human Right to Water
IANAS	Inter-American Network of Academies of Sciences
IRD	Research Institute for Development
IWRM	Integrated water resources management
JICA	Japan International Cooperation Agency
JMP	Joint Monitoring Programme
LTS	Large technical systems
MDG	Millennium Development Goals

MDRyT	Ministry of Rural Development and Land
MFE	Ministry for the Environment
MG	Municipal Governments
MMAyA	Ministry of Environment and Water
MMP	Metropolitan Master Plan
NES	National Environmental Standards
NGO	Non-governmental organisations
NMS	National Monitoring System
NPS	National Policy Statements
NRMMC	Natural Resources Management Ministerial Council
NRRP	Natural Resources Regional Plan
NWC	National Water Commission
NWI	National Water Initiative
OECA	economic organisations of peasants
OMAK	Aymara Women's Association of Kollasuyo
OTB	Territorial Base Organisations
PDC	Basin Management Plans
PDCK	Katari Basin Master Plan
PESFA	Strategic Triennial Sustainability Plan for Water Sources
PML	Clean Production
PMMAPS	La Paz - El Alto Metropolitan Master Plan for Water and Sanitation
PNC	National Basin Plan
RAR	Regulatory Administrative Resolutions
RASIM	Environmental Regulations for the Industrial Manufacturing Sector
RBMP	River Basin Management Plan
RCPA	Regulation of Environmental Prevention and Control
RGGA	General Regulation of Environmental Management
RMA	Resource Management Act of 1991
RMCH	Regulation on Water Pollution
SARH	Self-Supply Systems for Water Resources
SDG	Sustainable Development Goals
SENARI	National Irrigation Service
SENASBA	National Service for Sustainable Basic Sanitation Services
SES	Socio-Economic System
SGM	Sustainable Groundwater Management
SIG	Geographic Information Systems
SGM	sustainable groundwater management
SWM	Sustainable water management
UCAB	Aymara and Quechuas Union of Bolivia
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
UTAQ	Union of Knitters Aymaras and Quechuas
UTP	Technical Unit of Dams
VRHR	Vice-Ministry of Water Resources and Irrigation
WFD	Water Framework Directive

WHO World Health Organization
WUA Water user associations
WWTP Water Treatment Plant

Chapter 1 Introduction

1.1 Background

Water is a finite resource that is an essential component of life on Earth and vital services. Water supports human, animal and plant life while providing services fundamental for the livelihood and well-being of the population around the world (UNESCO, 2016). Through the hydrologic cycle, drinking water is provided to us in form of rain and surface water, for example, rivers, lakes, lagoons, and groundwater. The availability of drinking water is currently affected by rapid growth of population worldwide, increasing pollution, climate variability and unsustainable management, affecting the quantity and quality of these resources, particularly for groundwater resources.

Due to the increase in consumption through agricultural activities and for economic purposes, exploitation of groundwater has been increasing over the last decades (J. A. A. Jones, 2009). It is estimated that 20% of the world's aquifers are being overexploited (Gleeson, Wada, et al., 2012) leading to adverse impacts on groundwater quality and quantity (depletion of water levels, pollution, and potential effects of climate change, for example) (der Gun, 2012), and moreover, leaving 2.5 billion people, who rely exclusively on groundwater resources (UNESCO, 2016), without a safe source of drinking water. The finite nature of this resource compromises their capacity to generate social and economic benefits, driving the population towards an increasingly serious global water deficit. This has raised international concern, leading to the promotion of sustainable management for groundwater sources.

Sustainable groundwater management is needed to develop strategies that address resource availability, meet socio-economic demands while maximising development opportunities, maintain ecosystem integrity and environmental sustainability, include multi-governance levels, assure sustainable allocation of water, support resilience towards climate change and extreme events, while guaranteeing the right to water access (Esteban & Dinar, 2013; Gleeson, Alley, et al., 2012; Jakeman et al., 2016; J. A. A. Jones, 2009; Kinzelbach et al., 2003). Considering the complexity of these issues, the United Nations has established Sustainable Development Goals (SDG) for 2030 that aim to "ensure availability and sustainable management of water and sanitation for all." The objective promotes a broad and inclusive analysis of water issues, focusing not only on providing for drinking water and basic sanitation but including topics such as integrated water resources management, water quality, wastewater management, protection and restoration of water-related ecosystems, capacity building and stakeholder participation (UN WATER, 2015).

Even though efforts at sustainable groundwater management are occurring in some countries, there is currently a limited understanding of groundwater occurrence and use in Bolivia. Water management in Bolivia has always been inefficient because of a lack of policies and regulation (Alcocer, 2010). Most of the population does not have access to good quality water because of the lack of investment in infrastructure and technology (Buxton et al., 2013). Moreover, the country does not have the economic capacity to pay for scientific studies to explore in detail the physical and chemical characteristics of water resources. The companies in charge have issues with infrastructure, tariff regulation, financial sustainability and inefficient operation of services (MMAyA

& VRHR, 2014b). There are no current management approaches for groundwater, nor any initiatives to promote a sustainable use of this resource in the country (Alcocer, 2010).

Under those circumstances, this study will develop a sustainability analysis for the sustainable management of the Purapurani Aquifer in Bolivia (“the Aquifer”). This approach will help us to develop an understanding of the framework of the Aquifer system and identify the response of the system to adversities at different spatial and time scales. This provides an operational basis for defining sustainability (Jenkins, 2015c). This approach considers resilience as a key property to achieve sustainability, by analysing the capacity of the Purapurani Aquifer to “absorb disturbance and still retain its basic function and structure” (Jenkins, 2015a, p. 2). The results of the Sustainability Analysis will be presented with linked adaptive cycles for the Purapurani Aquifer, the critical variables for the management of issues and the thresholds associated with them. Moreover, it provides an analysis of current management interventions for each phase of the adaptive cycle, and proposes management interventions and institutional arrangements to promote a sustainable management of the Aquifer, that can potentially be replicated in other aquifers in the country.

These observations are significant for the development of the study, due to its adaptive and analytic nature, identifying deficiencies and strengths in these approaches that help to achieve the study’s goal. The study will provide wider and concise management options by suggesting effective planning strategies and management processes.

1.2 Problem statement

Groundwater resources in Bolivia have not been effectively regulated or managed in relation to their exploitation and development. Currently there is no policy for sustainable use, and limited information regarding the availability of the resource throughout the country. Because of this, the study develops a sustainability analysis to promote a sustainable use of groundwater resources in the country. As a result, the study will provide the government of Bolivia with management interventions to effectively manage groundwater resources, considering future demands and environmental challenges by building the knowledge and capacities in the institutions responsible for its management and the community.

The study considers the Purapurani Aquifer in the region of La Paz as a baseline to develop a sustainability analysis framework, complementary to the current management plan, as an example for future management strategies, by gathering and analysing information from international policies and management experiences; its aim is to provide management guidance. The study considers the concerns of the community, engaging them in the management process, and providing information and conditions to achieve sustainable management of future groundwater resources in the country.

1.3 Research aims

This project aims to provide a sustainability analysis for the use and management of groundwater resources in Bolivia based on the Purapurani Aquifer in the La Paz region. The project will identify critical management issues regarding the management approaches for the aquifer and will suggest sustainable measures that can be implemented for future development based on international experiences. The project will also collect and analyse environmental and legal information, and so provide an overview of the current situation of the Aquifer.

1.4 Objectives

The key objectives of this project are thus to:

- Collect groundwater information and data available for the Purapurani Aquifer and its current management to develop a sustainability analysis.
- Generate information regarding the current use and management perceptions of the authorities, stakeholders and community representatives to develop an overview of the current situation of the Purapurani Aquifer.
- Develop a comprehensive literature framework based on information and data gathered regarding hydrogeological, legal and socio-economic aspects of the Purapurani Aquifer.
- Identify and analyse failure pathways in the management of the Aquifer in order to provide management interventions for current and future issues of groundwater exploitation.
- Suggest sustainable management measures for the management of groundwater resources in Bolivia, based on the Purapurani Aquifer.
- Produce an informative document for stakeholders and communities with the purpose of promoting sustainable use of groundwater in the Purapurani Aquifer and providing information about the current state of the Aquifer.

1.5 Thesis structure

The development of the thesis is organised in six chapters. Chapter 1 introduces the research topic, presenting the study problem, the fundamentals of its choice and the location of the study area. It details the objectives that guide the study and its purpose. Chapter 2 contains sections on the main antecedents that are the basis for this research, as well as the fundamental theoretical concepts guiding the study's framework.

Chapter 3 describes the methodologies, materials and tools used in the different stages of the research. Chapter 4 contains the results of the investigation and a preliminary development of a sustainability framework for the Purapurani Aquifer. It is divided into three sections, in which the information is analysed: biophysical characteristics of the groundwater resources in the Purapurani Aquifer; socio-economic and legal information regarding the use and management in the urban/rural and peripheral communities of the area under study; and interviews of the actors involved carried out during field work.

Chapter 5 integrates the results under a nested adaptive approach, identifying the main strengths and weaknesses of groundwater management in the study area. The section provides the identification of adaptive cycles, failure pathways, critical variables and thresholds, and finally identifies and proposes management interventions for the sustainable management of the Aquifer.

To conclude, Chapter 6 presents the most important conclusions derived from the research, the policy options and some general recommendations based on issues identified on the development of the study.

Chapter 2 Literature review

The following chapter contains theoretical concepts that guide this study. It is important to recognise and identify these concepts for further development of this study, in order to avoid confusion and misconceptions. It is composed of four subsections that present essential information to develop a complete understanding regarding the current situation of the management of water resources globally and in Bolivia, in Subsections 2.1, 2.2, 2.3 and 2.4 respectively.

In accordance with the aim of this study, this chapter provides an overview of the groundwater management strategies emphasised in the concept of sustainable groundwater management. Subsection 2.3 provides an overview and analysis of international management approaches that have developed frameworks in order to achieve a sustainable management of groundwater resources. Understanding strengths and weakness of these case studies will support future management measures that this study aims to recommend to improve groundwater management in Bolivia.

2.1 Overview of water resources management

2.1.1 Why manage water resources

Water is essential for sustainable development, poverty reduction, economic growth and environmental sustainability through the many services it provides. We understand water resources as a renewable natural resource, but it should be perceived as finite, as explained by Loucks et al. (2005). When the situation is analysed, at current exploitation rates, water resources cannot renew as rapidly as is assumed and, in most cases, the limits to the amount of water that can be extracted from surface or groundwater sources are exceeded. There is evidence that these sources are reaching their exploitation limits and others have already been overexploited and have exceeded their limit; these can be described as a “mismatch between what humans expect or demand, and what nature can supply” (Gleeson, Alley, et al., 2012, p. 21).

According to United Nations data (2014), the world population is growing by 80 million inhabitants per year, increasing the pressure on water resources to provide for the demands of the population, industrial and agricultural uses, and energy generation. As a consequence, many countries in the world have experienced stress in the availability of their water resources. One index of water stress analyses the amount of renewable water available per capita in a specific area, the scale used by UNESCO in their latest World Water Development Report for 2016. This report indicates that areas such as the Middle East and North Africa are currently facing “absolute water scarcity”, even though they registered freshwater withdrawals of 309.81 billion cubic metres in 2014, according to the public data of the World Bank (Google Public Data, 2016), as shown in Figure 2-1.

In addition to a constant rising demand for water supply, these resources are affected by various sources of contamination that directly affect its quality, aesthetic values and availability, reducing the benefits that can be obtained from them (Loucks et al., 2005).

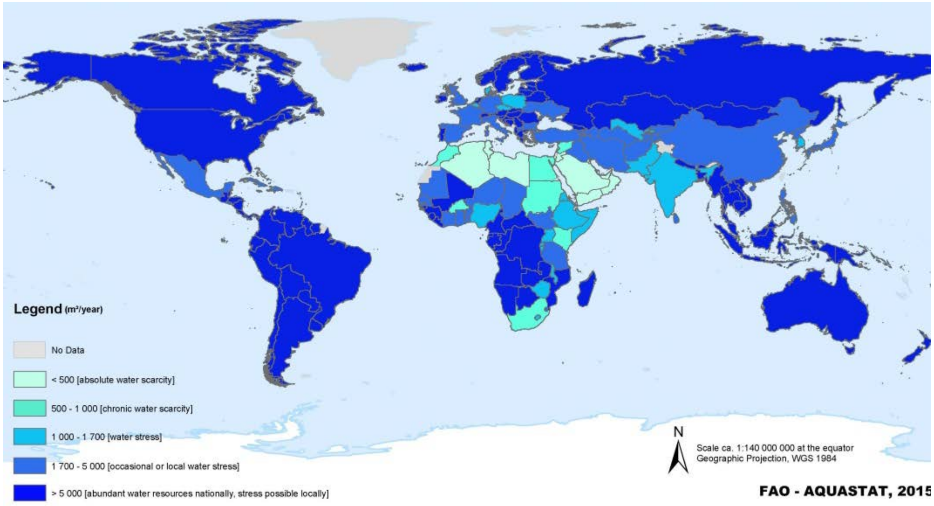

Figure 2-1 Total renewable water resources per inhabitant in 2014 (m^3/year). From UNESCO 2016, p. 16

Irrigation and drainage is another issue: the increase in global irrigation demand has driven the exploitation of water sources (surface and underground) at “exceptional rates” (Gourbesville, 2008, p. 286). There is evidence that groundwater resources have been overexploited in areas where the resource is limited, particularly in semi-arid regions. Because irrigation is an indispensable activity for human development and well-being, water resources management faces a challenge to develop strategies that can not only develop a mechanism that ensures the availability of water resources for this activity, but also promotes the sustainable use and management of the resource.

The following quote by Loucks et al. highlights issues, concerns and future goals to achieve sustainable water management:

> How can this be accomplished in an environment of uncertain supplies and uncertain and increasing demands, and consequently of increasing conflicts among individuals having different interests in the management of a river and its basin? The central purpose of water resources planning and management activities is to address and, if possible, answer these questions. These issues have scientific, technical, political (institutional) and social dimensions and thus, so must water resources planning processes and their products. (Loucks et al., 2005, p. 4)

Based on this information, it is clear that water is facing a crisis today. Demand for fresh water will continuously increase, and supply will be more limited, causing the population to face an increasingly serious global water deficit.

2.1.2 Water resources management approaches

Historically, management approaches around the world focused on the development of water resources in order to satisfy population demand and maximise economic benefits, but failed to include environmental and social variables. As pointed out by Loucks et al. (2005), planners and authorities managed to “...provide more high-quality water to irrigation areas in the basin at acceptable costs” (p. 21), but failed to include the dimension related to environmental potential and exploitation limits.

Management strategies have been developed under two general approaches: top-down and bottom-up, and recently the concepts of integrated water resources management have been introduced. In the following paragraphs, an analysis of these approaches and their influence in water management strategies and their design is provided. This analysis is important for future suggestions in sustainable management interventions for the Purapurani Aquifer.

Top-down and bottom-up approaches

The top-down approach has been used for the design of most water management strategies; this approach is generally focused on the design from a wider perspective in order to get to the nature of the issue meant to be solved. Loucks et al. (2005) exemplifies this approach as the "multipurpose master development plans" that have been developed in many countries with the objective of managing watersheds and basins. Most of these master plans prioritise the development of information in vast and various reports focused on technical information, and finally implement management measures with little active participation of stakeholders, private sectors or the community (Loucks et al., 2005). As a result, the popularity and effectiveness of this approach has decreased, causing the goals and objectives of the plans to be not achieved over time due to their "legally-mandated" nature, as identified by Sabatier (1986) p. 22. This particular observation relates to the current situation in Bolivia regarding the policies and management strategies that are based on this approach.

On the other hand, Sabatier (1986) identified some useful characteristics of this approach, such as the "formulation-implementation-reformulation cycle", which allows the identification of deficiencies in the management programmes, while improving them over time. Similarly, the management objectives with legally-mandated character ensure implementation, despite future changes of legal documents or the influence of political views in long-term periods. This approach can be considered as a "results-based management" approach (Fraser et al., 2006, p. 118). Although this may be true, most of the time these objectives are proposed based on a technical nature and are supply-driven particularly for development and other economically inclined purposes. Gourbesville (2008) points out that the engineers' point of view should be "adapted and extended" (p. 286) in order to consider the technical design of infrastructure equally as important as socioeconomic and environmental assessment.

The bottom-up approach starts by identifying the actors involved in the management issue, community and stakeholders (at the bottom), acknowledging and analysing their perspective and influence in the development and establishment of management objectives (Fraser et al., 2006; Sabatier, 1986). The active participation of the community can ensure implementation of management plans over time, while building capacities within the community that will help them to address future problems (Fraser et al., 2006). Additionally, this approach also facilitates the processes of dealing with problems and issues raised by the community in a direct and efficient way, thanks to the networks and contacts established in prior stages. Another key point is that this approach is unlikely to face social rejection of its objectives and management measures because they were included in the development process. The objectives will mostly reflect the opinions of the community and address the issues identified by them.

One of the limitations of this approach can be identified as a future clash with policy objectives, governmental and private programmes, as described by Sabatier (1986). While this approach prioritises the current actors and their necessities, most of the related issues and management approaches can be foreseen and not considered in the first level of analysis (Fraser et al., 2006). The approach fails to analyse direct and indirect factors that influence the perceptions and opinions of the actors and stakeholders (Sabatier, 1986).

It can be concluded that the top-down approach is more effective in policy implementation, and the bottom-up approach more significant in the process of policy formulation, and when choosing either of these approaches, decision makers must first establish the priorities and evaluate the interests and conditions of the area to assess the appropriate approach. Such observations lead to the development of a management strategy that promotes a cohesive vision for the management of water resources: integrated water resources management.

Integrated water resources management (IWRM)

World water concerns are increasing over time, with a need to develop an interconnected management strategy that involves social, economic, legal and political factors (Biswas, 2004). Assessing uncertainties with supply, social conflicts and the increasing demands on water make reconciling divergent needs no small task, especially as the variability of hydrological and hydraulic processes becomes more pronounced, and as stakeholders' measures of system performance increase in number and complexity (Loucks et al., 2005). These issues have been identified as a basis for the development of an innovative management strategy that nowadays is often used by decision makers and policy developers; this strategy is known as integrated water resources management (IWRM).

The concept has been developed since the 1980s, according to Loucks et al. (2005), on the basis of the principles in the Dublin Statement on Water and Sustainable Development (World Meteorological Organization, 2016):

> a) Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment, b) Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels, c) Women play a central part in the provision, management and safeguarding of water, d) Water has an economic value in all its competing uses and should be recognised as an economic good (World Meteorological Organization, 2016, p. 2).

Based on this definition, the IWRM is composed of three main principles: economic efficiency, equity, and environmental sustainability, as shown in Figure 2-2.

IWRM focuses on promoting coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner (Jakeman et al., 2016). These goals can be idealistic and difficult to achieve, especially when it aims for equitable welfare while considering long-term goals. Biswas (2004) proposed a reassessment of the definition of IWRM by evaluating uncertainties such as lack of an objective conclusion and definition mechanism that will measure the criteria, relevance and usefulness of the concept. This observation shows the importance of establishing parameters to monitor and evaluate plans, programmes and initiatives developed under this framework.

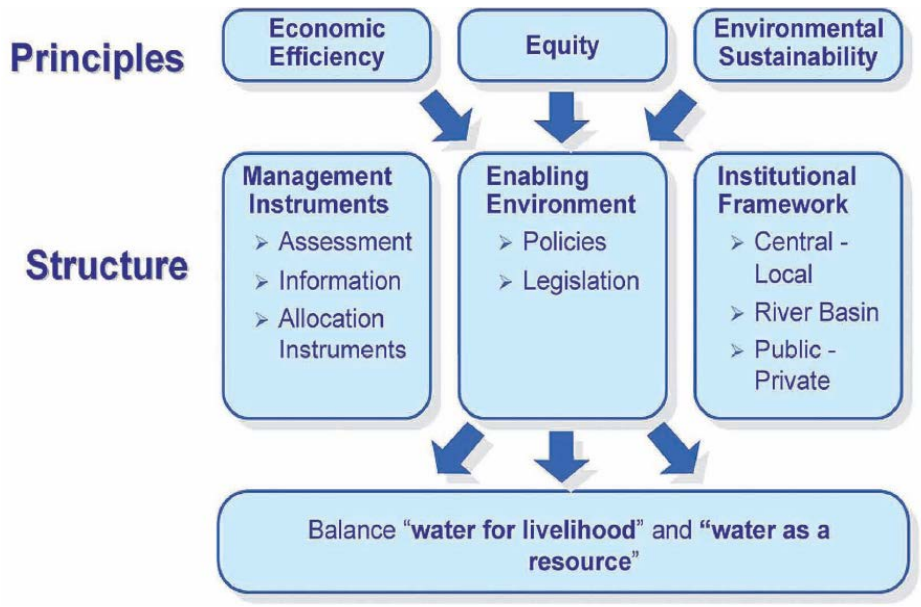

Figure 2-2 IWRM components. From Hassing, 2009, p.4

IWRM is consider as the pathway to achieve sustainable development, but not the goal itself; the need to establish goals that can be measured and monitored in different periods of time will ensure the achievement of sustainable management (Gourbesville, 2008). It is important to recognise that water and other resources are interrelated and interdependent, so when planning or developing a management strategy it is necessary to identify overlaps and linkages between water, natural resources, institutions, ecosystems, and other parameters that might influence the resource (Biswas, 2004). This is a critical issue involving both developing and developed countries. Most countries will face two major issues according to Gourbesville (2008): law and regulatory challenges (developing laws and creating regulatory institutions), and develop and maintain water infrastructure.

The implementation of IWRM may vary depending on the characteristics of the region or country, but generally the planning cycle of IWRM follows seven stages as shown in Figure 2-3. The cycle starts by establishing overall goals, considering international and national frameworks and developments, followed by a collaborative-build commitment process in order to engage stakeholder dialogue and participation – both stages are complementary to each other.

This particular stage is not recognised as an independent step and is usually assumed as a component of the subsequent stage, which is focused on analysing water resources issues. As mentioned above, IWRM needs to prioritise participation and promote ownership by stakeholders to be an effective planning tool. This situation occurs between stages 3 and 4 as well, which considers stakeholder acceptance and political adoption as components of the development of a water resource strategy or action plan stage and its implementation, but fails to identify stakeholder acceptance and participation as an essential step from strategy development to implementation. By recognising the importance of local participation in the IWRM processes, ownership, involvement and capacity building are promoted, "reducing possible misunderstanding and misconceptions among stakeholders" (UNEP, 2010, p. 9). The final stage monitors and evaluates the progress of the IWRM strategy: as components of this stage it is necessary to previously establish indicators that clearly identify progress or failure of the strategy. Finally, the cycle comes back to the first stage in order to assess if the goals established at the first stage have been achieved, or else to identify new activities or approaches that should be included in order to update and improve the IWRM strategy.

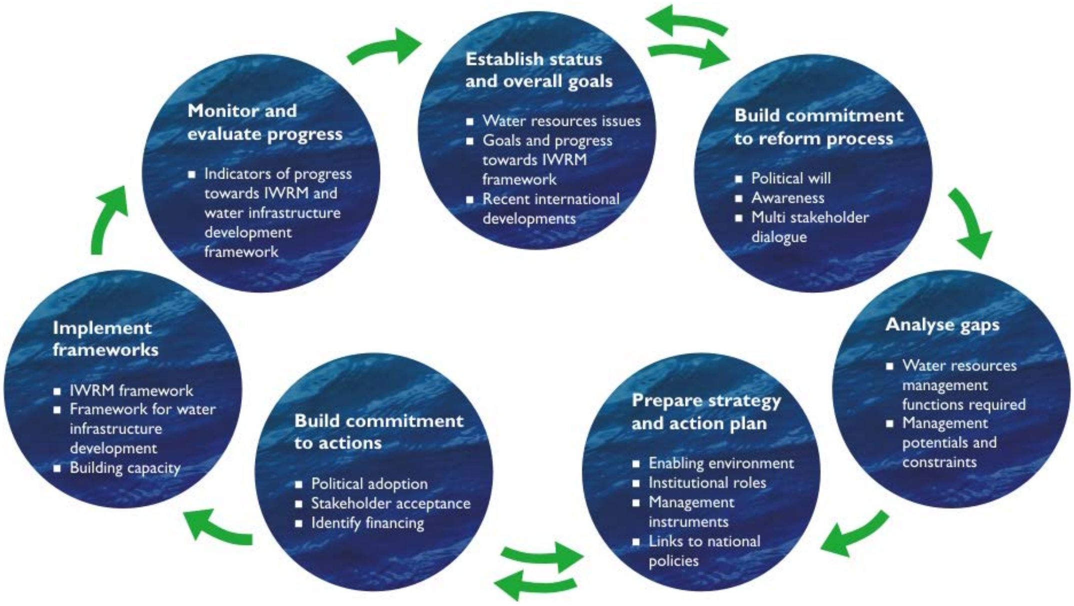

Figure 2-3 The IWRM planning cycle. From: Global Water Partnership, 2013.

The question many studies and strategies face now is how to *effectively* achieve an IWRM that is operationally achievable and integrates with the countries or area where it is implemented. Planners will need to consider future positive or negative impacts, environmental characteristics, and future changes (climate change effects), indicators, achievable goals, suitable time frames and how effective this strategy will be in a given area. In order to answer these queries, it is important to collect information and data on previous, current and future conditions of the environment; economic and social statistics; the legal framework; and political views .

A study developed by the United Nations Environment Programme (UNEP) in 2010, compiled studies and experiences from various countries, obtaining references to improve IWRM strategies for future development. The major lessons learned involve issues such as local ownership and stakeholder participation, sharing of experiences and information, links between IWRM activities to current national processes and frameworks, and development of adaptable approaches (UNEP, 2010). By addressing these issues and complementing such activities, IWRM goals are more likely to be achieved.

2.1.3 Sustainable water management (SWM)

It is evident that water scarcity is likely to affect the well-being of populations worldwide, and limit opportunities for economic growth in the coming decades. The issue is that there is not enough water for all, on top of a crisis of sustainable governance (Loucks et al., 2005) and unsustainable consumption. This is where the concepts of sustainable development and sustainability are introduced.

Sustainable development is defined as a “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987 cited in Medema & Jeffrey, 2005, p. 4). This concept is focused on three pillars: economic, socio-political and environmental conditions. As a result, sustainable water management attempts to enhance and preserve water resources, while providing for the necessities of social, economic and environmental systems, and ensuring water security for all (Flint, 2010).

Another fundamental and complementary concept in sustainable water resources management will be *sustainability*, even though the precise definition is under constant debate and its meaning is subject to people's perceptions. Schnoor (2013) describes water sustainability "as the continual supply of clean water for human uses and for other living things". In contrast, Mejía et al. (2012), adopt the definition whereby "water resources and water services are able to satisfy the changing demand placed on them, now and into the future, without system degradation" (p. 4). We can identify that under both approaches for a definition, the concluding goal of sustainability is to preserve the "welfare of those living in the future" as identified by Loucks et al. (2005, p. 23).

Incorporating both concepts in water management agendas leads to sustainable water management in the future, as Varis et al. (2014) suggest*:* "when it comes to governance and sustainable development, the fad of the day is integration" (p. 433).

In order to achieve sustainable development, water as a fundamental resource needs to be properly managed and preserved. This issue is recognised by the United Nations (UN), which has established Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs) to be achieved by 2030 in order to achieve sustainable development and water sustainability (Hering et al., 2016, p. 6122). The SDG 6 sets out to "ensure availability and sustainable management of water and sanitation for all". The objective promotes a broad and inclusive analysis of water issues, focusing not only on providing for drinking water and basic sanitation but including topics such as integrated water resources management, water quality, wastewater management, protection and restoration of water-related ecosystems, capacity building and stakeholder participation(UN WATER, 2015).

The World Bank Water Resources Management Strategy focuses on the connections between the resource and the service management (UN WATER, 2015). Gourbesville (2008) resumes this approach, highlighting four components addressed:

- **the institutional framework** – defining local and international management institutions involved in the management of the water resources
- **the management arrangements –** identifying regulatory framework, standards, plans, financial instruments and participation mechanism
- **the development and management of infrastructure –** in order to have information for future adaptive measures and to protect water quality and sources
- **political reforms –** to develop and encourage a productive and sustainable water use.

All aspects considered, in order to manage water within the framework of SWM, environmental boundaries need to be recognised to avoid unforeseen changes that may affect the management measures proposed (Flint, 2010). It will be important to develop management strategies that consider future changes in the environment and their influence in other resources, economic activities and spatial scales (for example, region and nation). Finally, establishing "sustainability" indicators to measure performance and achievement will also help identify water resource criteria unsuitable for the area of implementation.

2.1.4 Where to improve current water resources management approaches

The technical nature of policies of the past proved to be locally unsustainable and unacceptable because water resource management in an area needs to deal with a resource that integrates basic human rights and is central to all life (Biswas, 2004).

Future development of scenarios must analyse the current situation, driving forces and uncertainties, time frames and external influences. The driving forces identified by Gallopín (2012) are: demographic; economic; technological; water resources; water infrastructure; global climate change; environmental activities; social, cultural and ethical aspects; education and formation; institutional structure and governance; and political views and trends, as shown in Figure 2-4. These do not represent an exclusive list but identify areas claimed to be significant for water management. These driving forces will be considered and analysed in the following sustainability analysis in this study.

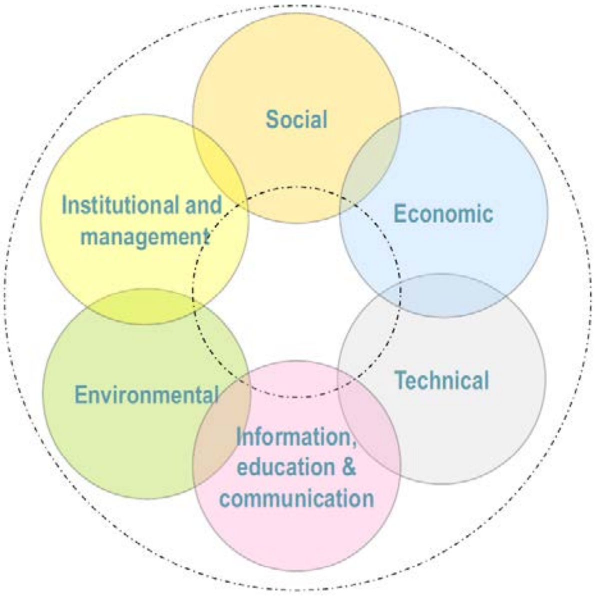

Figure 2-4 Driving forces for a sustainable water management. From Walmsley et al. 2010, p. 195

Planning processes must consider hydrological facts and conditions easily affected by change over time, as identified by Loucks et al. (2005, p. 26): "planning processes evolve not only to meet new demands, expectations and objectives, but also in response to new perceptions of how to plan more effectively". Plans should be adapted to common language applicable from local to national and regional levels (Kennedy et al., 2009), should include mechanisms to change ways of thinking, and guarantee the right to water without discrimination, and with equality between men and women (UNESCO, 2016). In this context, decision makers must prioritise the fulfilment of the human right to safe drinking water and sanitation over competing uses and economic sectors, while supporting the implementation of greener and more productive practices.

Successful management plans will provide reasonably consistent objectives, good base theory, community involvement in decision making, sympathetic implementation mechanisms and adequate financial resources (Sabatier, 1986). Policy makers must ensure a clear evaluation of legal resources (past, current and future), establish clear objectives, analyse policy interventions and effects on social change, establish regulatory mechanisms (sanctions and incentives to overcome resistance and promote implementation or acceptance), and assign responsibilities to institutions. Policies must adopt an adaptive character to promote a periodic revision of statutes and measures due to changes in stakeholders' interests and observations, and environmental and socio-economic conditions, in order to ensure policy effectiveness (Huitema et al., 2009).

Many developing countries face the issue of finance due to limited internal resources; if this is the case, decision makers must establish a mechanism to search for and centralise investment and finance sources. Investment in infrastructure can provide significant economic growth, for example, new job opportunities, water security and technological development, among others (UNESCO, 2016). Complementary infrastructure investments and components such as land use planning, watershed management, management information systems and monitoring programmes should be included.

Loucks et al. (2005) define water resources planning and management "as creating a social environment that brings in all of us who should be involved, from the beginning in a continuing planning process" (p. 24). This inclusive process will assess the current state of water resources; identify existing and potential options and opportunities for development; provide a regulatory framework; promote ownership; facilitate and promote participation of stakeholders; share information while enhancing capacities; and resolve equity and equality conflicts.

2.2 Groundwater – current situation and management approaches

Groundwater is the water stored beneath the Earth's surface in soil and porous rock aquifers (Famiglietti, 2014). Groundwater is a vital component in the water cycle and is a life-sustaining resource. Groundwater represents at least 98% of drinkable water that is not frozen, and around 30% of total freshwater in the world (UN WATER, 2014). It supplies at least 50% of the world's population with drinking water and accounts for 43% of all water used for irrigation (FAO, 2010 cited in Connor, 2015). The statistics clearly show the significance and importance of this resource to development, to supply for population water needs, and maintaining the sustainability of ecosystems.

The extraction of groundwater has increased during the last 50 years, due to its abundance, high quality and reliability, and to advances in hydrogeology that facilitate its extraction at a relatively accessible cost (UN WATER, 2014). At the present time, groundwater resources are being overexploited, leading to a depletion of the resource – currently 20% of aquifers worldwide are depleted (Connor, 2015). This is a consequence of exploitation rates exceeding the natural renewable process, and of contamination, lack of planning, and poor management and monitoring.

The general effects of overexploitation of groundwater include water level drawdown, degradation of water quality, contamination, land subsidence and environmental impacts (Findikakis, 2011). As these effects increase, many countries have started to gather information about this resource in order to improve its management, regulate its exploitation, develop approaches to protect it from current impacts, and ensure its availability for future generations (Findikakis, 2011).

The challenge is to change from "uncontrolled to managed groundwater use", as highlighted by Findikakis (2011). Management approaches and tools must consider climate change influence in recharge rates, raise awareness to improve groundwater quality and protection, develop information to improve knowledge of the aquifer system and implement new methodologies and technologies that help control and reduce the impact of overexploitation of the aquifer by planning and establishing medium and long-term objectives (Esteban & Dinar, 2013; Gleeson et al., 2010; Jakeman et al., 2016). This establishes an overall goal to manage groundwater resources in order "to provide sufficient water to sustain urban, agricultural, industrial, commercial and environmental needs over time" (AWWA, 2014, p. 35), introducing the concept of sustainable development in groundwater resources.

2.2.1 Sustainable groundwater management (SGM)

For thousands of years the sustainability of groundwater resources was not in question because of smaller populations and practical limitations that prevented the abstraction of large quantities of groundwater, but now with improvements in technology and an increasing demand, the concept is highly investigated and implemented.

The concept of sustainable groundwater management (SGM) lies in the basis of sustainable development and sustainability, which have been covered in Section 2.1.3 of this study. Sustainable development of groundwater is categorised as multifaceted and complex by Alley et al., (1999) due to the many connections and interdependencies with other resources, the environment and society. Various reports discuss the relationship of groundwater sustainability with the concept of safe yield, which is defined as "the quantity of water that can be pumped regularly and permanently without dangerous depletion of the storage reserve" (Seward et al., 2006, p. 473). Many similarities can be identified between the concepts, such as analysis of water quality, quantity and economics; but the safe yield approach fails to address environmental and social aspects in the management of groundwater. Based on this observation, this study will use the concept of SGM.

Gleeson, Alley, et al. (2012) identify SGM as a process that balances environment, society and economy with intra- and intergenerational equity, evaluating short- and long-term scenarios and effects. Consequently, priorities for SGM have been established (Gleeson, Alley, et al., 2012) that include:

- sustainable long-term goals and exploitation rates of the aquifers
- effective use of the large volume of water stored in aquifers
- preservation of groundwater quality and aquatic environment
- integrated analysis of groundwater and surface water into a comprehensive water and environmental management system.

Given these points, effective management approaches must consider all management strategies in order to develop a resilient and adaptive management tool that will be able to protect groundwater quality and quantity, while maintaining the balance with economic activities and social demands, and sustain the environment in short- and long-term scenarios. An effective groundwater sustainable strategy will set long-term goals, and will use back-casting and adaptive integrated management. The use of back-casting helps to identify sustainability goals, and identifies policies and programmes that connect the future to the present (Gleeson, Alley, et al., 2012). Under those pointers, different tools are needed to predict future trends and develop scenarios.

To facilitate the implementation of an SGM strategy, and due to the complexity of groundwater systems, it is necessary to generate information based on technical tools such as field mapping, remote sensing, well drilling, geophysical logging, survey and information systems, groundwater quality and quantity analysis, flow modelling, and risk assessment, among others, as identified in Table 2.1 (Foster & Loucks, 2006b). It also important to recognise that groundwater systems and other natural resources (for example, surface water, soil), are interdependent and interconnected. They also influence regional or local development and social behaviour in the stages of exploration, development, and management.

Investing in technology upgrades and developing capacities to implement them becomes a crucial aspect to first understanding groundwater systems in order to identify issues and propose measures that address them. These tools are commonly used in the hydrological characterisation of an aquifer; identifying which technical tools would be needed at a specific stage facilitates assessment and speeds up the process of gathering information.

Although these investigation tools are standard for hydrogeological characterisation, there are also other tools that must be included in the overall analysis. Socio-economic and legal information should also be prioritised in order to develop a complete overview of an aquifer. The influence of these sectors, in the processes of both developing and implementing management measures, is significant and directly influences both the effectiveness and achievement of sustainability goals. Many successful strategies will need the active participation of stakeholders, institutions, community, and, most of all, water users, in support of better management. Educating water users and building capacities is crucial for sustainability, as noted by Alley et al. (1999): "Knowledge about groundwater is an indisputable prerequisite for a sustainable use of water as a valuable natural resource".

The information provided above reinforces the need to introduce the concept of sustainable management of groundwater resources with the support of scientific tools and management strategies. The following section gathers international experiences and strategies to develop an overview of groundwater management approaches.

Table 2-1 Summary of hydrogeological tools to guide groundwater development and management

TOOLS	EXPLORATION Groundwater use only for rural subsistence	DEVELOPMENT Introduction of improved drilling and pumping technology	MANAGEMENT Groundwater level decline and possible quality deterioration
Field mapping and remote sensing	Definition of aquifer extension/ structure and potential recharge areas	Identification of areas for intensive resource development and possible impacts of reduced aquifer natural discharge	Checking groundwater production from agricultural crop-use and status of natural discharge areas
Regional geophysical surveys	Complements mapping of surface geology	Improves identification of more productive aquifer zones (include use of aeromagnetic techniques)	Further refinement possible but not widely used
Waterwell drilling	Exploratory for reconnaissance level data on hydrostratigraphy	Production wellfield construction with associated infrastructure (usually either for urban water-supply or irrigated agriculture)	Refining production system to provide maximum energy efficiency; in some cases waterwell rehabilitation and pump replacement
Downhole geophysical logging	Improves hydrostratigraphic analysis	Improves correlation between waterwells and refines aquifer conceptual model	Aids diagnosis of waterwell yield and quality problems, and thus facilitates rehabilitation
Geographical information systems	At best simple manual databases of geo-referenced hydrogeological data	GIS-based information systems for well records and aquifer data – output well-suited for input to numerical aquifer models	GIS transformed into MIS for data on aquifer production performance and socio-economic indicators
Groundwater chemical and isotopic analysis	Reconnaissance-level determination of groundwater genesis and chemical variations	More detailed evaluation of groundwater genesis and evidence of contemporary recharge	Evaluation of rates of contemporary recharge and prediction of groundwater quality changes threatening wellfields
Analytical radial groundwater flow models	Analysis of pumping test data for estimation of aquifer properties	Prediction of drawdowns for waterwell design	Analysis of causes of well deterioration and rehabilitation planning
Lumped-parameter aquifer models	------------------	Basic aquifer water balance to confirm conceptual model	Mass-balance type checks on issues such as 'life of resource' or 'bulk impact of production'
Numerical distributed-parameter aquifer models	------------------	Testing conceptual model validity, optimising wellfield design/production and determining potential long-term impacts	Improving operational efficiency and evaluating long-term sustainability of wellfields
Groundwater development risk assessment	------------------	Assessment of risks of premature failure/quality deterioration of wellfields	Assessment of risks to groundwater-based economic development related to externalities, such as changes in energy costs and crop prices

Note. From Foster & Loucks, 2006b, p. 37

2.3 International groundwater management strategies and policies

This section outlines international case studies in order to analyse their management approaches and policies to accomplish a sustainable management of groundwater resources. This section supports the aim of the study by identifying positives outcomes and lessons learned in the international strategies selected. These international management approaches, the decision-making processes, and stakeholder participation, as well as their limitations, are highly significant to this study. The studies selected are:

- Resource management approach in New Zealand and groundwater management in Canterbury
- European Groundwater Framework Directive, and Spain as particular case study
- Use of groundwater resources in Saudi Arabia: Management and Policy Options
- Groundwater legislation tools in China
- Groundwater legal framework and management practices in western USA
- Groundwater management framework Australia and the Great Artesian Basin approach.

These studies were chosen due to the effectiveness of the management frameworks and similar area characteristics with the country of study, Bolivia, and the likelihood of replicating these approaches in the Purapurani Aquifer. At the end of the chapter, a concluding section is provided, summarising the strengths and weaknesses of these case studies that will guide this study in the management interventions section.

2.3.1 Resource management approach in New Zealand and groundwater management in Canterbury

Groundwater is a valuable resource in New Zealand, in particular for the region of Canterbury; the region relies for its development mostly on the availability of this resource (Lowry et al., 2003). For this reason, Environment Canterbury (ECan), the regional council of the Canterbury region, has developed a Natural Resources Regional Plan (NRRP) to manage natural resources in the area, along with a Canterbury Water Management Strategy (CWMS) to support it.

These management tools were developed under the regulatory framework for natural resources in New Zealand: the Resource Management Act of 1991 (RMA). The framework promotes a "sustainable use, development, and protection of natural and physical resources" as described by Lowry et al. (2003).

The applicability of the RMA is allowed through the administration tools shown in Figure 2-5: National Environmental Standards (NES), National Policy Statements (NPS), specific regulations, and water conservation orders (New Zealand Ministry for the Environment Manatū Mō Te Taiao, 2015). In relation to water management, the NES and the NPS for Freshwater Management (NPS-FM) provide requirements for freshwater management guidance and conservation; groundwater management is also contemplated. Regional and district councils develop policy statements and plans, for example NRRP or the CWMS, guided by these tools (New Zealand Ministry for the Environment Manatū Mō Te Taiao, 2015).

The RMA also identifies and appoints roles and responsibilities to primary governing and decision-making authorities: central government, local government, ministries, requiring authorities, and heritage protection authorities. The decision-making process under this framework directly involves the participation of stakeholders in the development of a management plan and its implementation through mechanisms of public submissions and appeals to the Environment Court (Lowry et al., 2003). Stakeholders can question the applicability, effectiveness and objectivity of the management measures suggested in the regional plan. In the case of no regional plan, those directly affected must obtain a resource consent from the regional council in order to use water resources. The analysis of this specific decision-making process is one of the reasons why the New Zealand resources management framework is considered in this study.

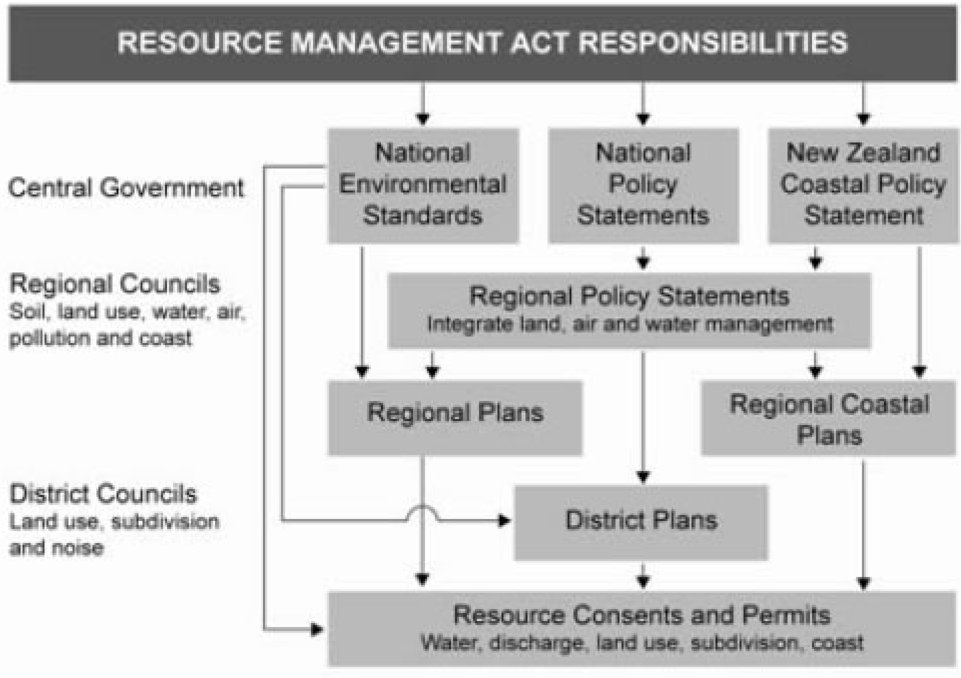

Figure 2-5 Resource Management Act responsibilities. From New Zealand Ministry for the Environment Manatū Mō Te Taiao, 2015

In order to assess the effectiveness of the RMA, the MFE implements a National Monitoring System (NMS), which requires authorities to evaluate each year the functions, tools, activities and processes implemented under the RMA (Ministry for the Environment, 2016).

In the case of Canterbury, the NRRP addresses groundwater management through the establishment of 30 Groundwater Allocation Zones, which have been identified based on the concept of sustainable yields (Aitchison-Earl et al., 2004), while the CWMS involves the participation of the community as a main role for the development of any management approach. This promotes an integrated vision to strategically assess scenarios on different aspects at any spatial level as part of the participatory planning process designed by ECan (Taylor & Mackay, 2016). This tool helps to develop a social framework basis while promoting a continuous revision of allocation limits and update of information while promoting ongoing monitoring.

The concept of “sustainability” combined with the concept of “safe yields” is used to establish limits lower than the average recharge rates and are helpful to establish a first management measure (Scott, 2004). If establishment of “safe yield” limits are considered and this approach is used, it must be adapted to the conditions and characteristics of the country and the environment where this concept may be applied. The way groundwater is managed in any location is dependent on the level of technical information known about the aquifer.

The groundwater zones were first allocated by establishing extraction limits based on rainfall and river recharge rates to provide an adequate and reasonably reliable supply of water (Aitchison-Earl et al., 2004), and recalculated every year based on information such as “rainfall and potential evapotranspiration (PET), land-use, and soil moisture characteristics” (Scott, 2004, p. 8). These limits address nutrient loads, water allocation and land management to protect the water quality and quantity of water bodies while including the participation of the community in the decision-making process, and considering economic and cultural characteristics (Taylor & Mackay, 2016). The limits were identified by a technical team formed by specialists, to guide local planners and affected communities and stakeholders with the aim of “developing a fair and optimum regime” as identified by Taylor and Mackay (2016).

As a result of this approach, the region identified three different categories that can be applied to a groundwater allocation zone. A red zone is an area that has reached or exceeded this trigger level. A yellow zone is an area where groundwater allocation is within 80% of this level. A white zone is an area where groundwater allocation is less than 80% of this level (Aitchison-Earl et al., 2004). This classification guides the authority in the decision-making process and in establishing management interventions.

As limitations, Taylor and Mackay (2016) identified a lack of social data necessary to build a baseline and a complete understanding of land uses, consumption trends and local knowledge. Social activities have effects on the environment, and both are influenced and connected with each other. Integrating the assessment of these areas facilitates the process of limit-setting through communication, accessibility, data management and sharing. Finally, it also identifies the requirement to develop future scenarios to deal with uncertainty and changes. Typically, baseline data goes back over 20 years and future scenarios attempt to look ahead 30 years, due to the complexity of groundwater systems and long timeframes necessary to evaluate their decline or improvement (Taylor & Mackay, 2016).

2.3.2 EU groundwater framework directive

In the European Union (EU), groundwater supplies 55% of the domestic demand and 33% of irrigation. The resource is of great importance for the development of the region (De Stefano et al., 2015). As a result, European countries have been working at regional, national and local levels in order to implement environmental management activities. Countries have agreed to work together to “improve current environmental water quality conditions in catchments and reduce adverse impacts occurring or likely to be caused” (Loucks et al., 2005).

In 2000, the EU implemented the Water Framework Directive (WFD) that promotes river basin management plans with cooperation and joint objective-setting across member state borders (European Commission, 2016b). The objectives must address the protection of the aquatic ecology, habitats, drinking water resources and bathing water (Jakeman et al., 2016).

The effectiveness of WFD objectives will be defined by the cooperation between member states’ environment agencies or ministries, the community, stakeholders, NGOs, the scientific community and the European Commission (Quevauviller et al., 2011). As a result, the operation of the WFD relies on its Common Implementation Strategy (CIS). As Figure 2.6 shows, directives established by the WFD promote an organised establishment of roles or responsibilities for each directive, and promotes collaborative governance between them; for example, the Groundwater Working Group gathers more than 80 experts who meet twice a year to exchange experiences, discuss technical difficulties about implementation, and develop guidance documents (Quevauviller et al., 2011).

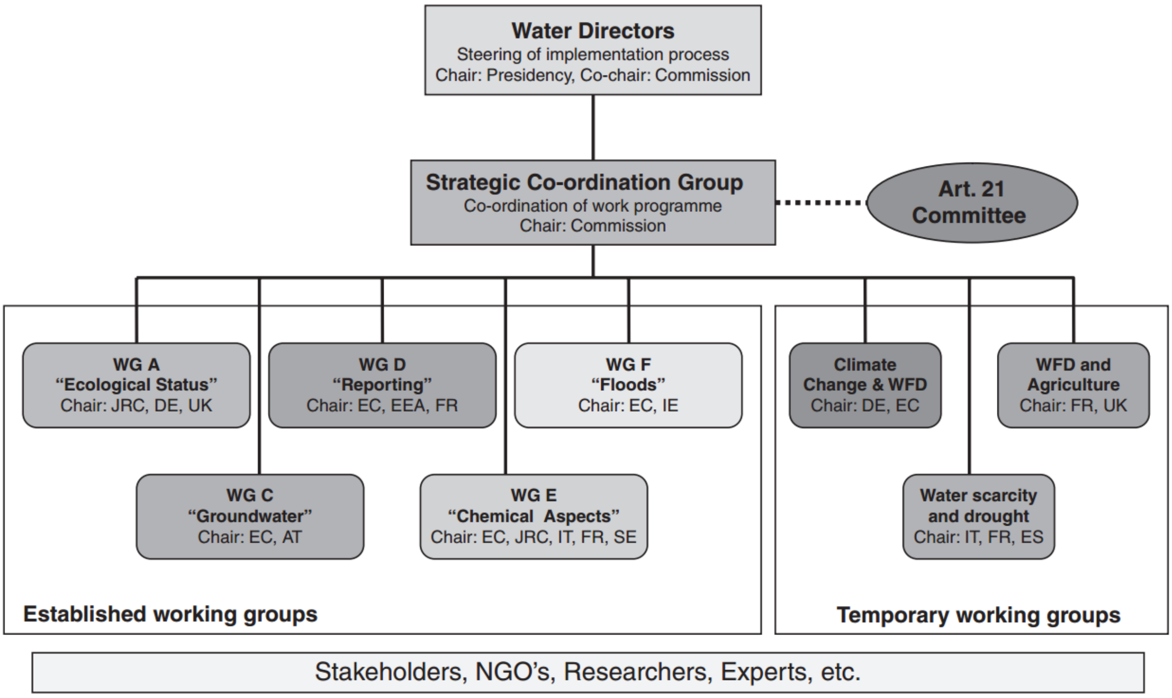

Figure 2-6 The Common Implementation Strategy (CIS) of the Water Framework Directive

Note. The Common Implementation Strategy (CIS) of the Water Framework Directive as operated during the period 2010–2012. Country acronyms are: AT (Austria), DE (Germany), DK (Denmark), EC (European Commission), EEA (European Environment Agency), ES (Spain), FR (France), IT (Italy), JRC (Joint Research Centre), NGOs (Nongovernmental organisations) and UK (United Kingdom). From Quevauviller et al., 2011, p. 312

The components of WFD related to groundwater focus on managing the chemical and quantitative status of groundwater resources (European Commission, 2016a). The ultimate aim of this framework is to ensure a balance between extractions and recharge of groundwater; for this reason, in 2006, the WFD created the Groundwater Directive, which will clarify analysis criteria and specifications regarding this resource (Ross, 2016).

The Groundwater Directive requires member states to define and characterise groundwater bodies within river basin districts and report the results to the European Commission. This characterisation must be developed in the knowledge of driving forces (D) e.g. agriculture; pressures (P) e.g. land use; status (S) e.g. environmental conditions; impacts (I) in nature or environment; and responses (R), which are the main components of a river basin management plan. The characterisation must include an analysis of the effects of human activity on groundwater quality, links to water uses and interactions with ecosystems, among others (Quevauviller et al., 2011). The integration of this component in a groundwater system can be assisted with modelling software like MODFLOW, MIKE SHE, FEFLOW and the other GIS tools.

The Directive also requires members states to develop a River Basin Management Plan (RBMP) and establish protected areas within the river basin districts for groundwater areas, or habitats and species directly dependent on water (European Commission, 2016a). It is expected that the RBMPs summarise information regarding pressures and impacts of human activity on groundwater status, as well as giving a comprehensive overview of its management. Under these circumstances, member states must also develop groundwater monitoring networks to evaluate groundwater chemical and quantitative status (European Commission, 2016a). The RBMP and monitoring programmes are to be reviewed every six years from its implementation.

It is also important to note that the Groundwater Working Group has developed key guidance documents in order to achieve these requirements – a guidance document on groundwater monitoring, a guidance document on compliance and trends, groundwater status and trend assessments, among others (European Communities, 2008). These documents guide Member States in the selection of tools and mechanisms necessary to provide an effective RBMP.

In regard to public participation, the WFD requires a consultation process and exchange of information with the stakeholders, professionals and the community (European Commission, 2016a). RBMPs are to be issued in a draft, shared with the community and subject to reviews every two years in a conference organised by the member states. This communication network must be established at early stages of the development of RBMPs to ensure enforceability and transparency with regard to measures and standards proposed in the basin plans (Jakeman et al., 2016).

Another key point of this framework relates to the availability of information of the WFD, guidance documents and other sources of information. The EU has developed a comprehensive online informative platform available to the public (Jakeman et al., 2016). This promotes the active participation of the community as well as promoting education and guidance.

As a particular case study of the EU, the following section analyses the implementation of the WFD management framework in this country.

EU Water Framework Directive – groundwater use in Spain

Spain, as an EU member state, has to shape its water policy in accordance with EU regulations, in this case the WFD. Based on this framework, there were 777 groundwater bodies (GWBs) identified across 70% of the country, which provide for 22% of Spain's total water demand (De Stefano et al., 2015). These GWBs have been recognised as a main source of water for instream flows during dry periods (De Stefano et al., 2015). The country also faces issues with abstraction rights, ownership and regulation. Water authorities at every spatial scale of management must elaborate management strategies, RBMP for example, acknowledging the importance of water users' participation, and must understand their traditions and customs in relation to groundwater bodies (Lopez-Gunn, 2003).

The domestic supply is regulated directly by municipalities, under a legal framework established by regional governments (De Stefano et al., 2015). Although this shows clear roles and responsibilities within regulatory institutions, rural communities are not always under the same legal framework as urban areas, and there is a tradition for collective water management under the water user associations (WUAs) (Lopez-Gunn, 2003).

The concept of collective water management promotes the integration of water users. In the case of the La Mancha aquifers in Spain, farmers, their leaders, and water authorities "built social capital and a solid institutional framework in which to introduce sustainable practices, which are sometimes deeply unpopular or difficult to implement without their internalization by farmers", as identified by Lopez-Gunn (2003, p. 377). There are some factors where this approach can be useful for the development of management strategies; it requires clearly defined boundaries between water services (irrigation or domestic use), inclusion of individuals affected by operational rules in agreements, a monitoring process and monitors who actively audit themselves or other users, graduated sanctions, conflict resolution mechanisms, recognition of users' rights and connection between all of the previous issues under "nested enterprises" (Lopez-Gunn, 2003, p. 375).

The observation above and the example of the La Mancha aquifers support the need to include all spatial water users in the development of a management strategy, which may also help to identify new roles and assign other responsibilities to community representatives.

Some of the approaches used to manage groundwater in the industrial sector are to control groundwater pollution mainly from industrial waste disposal and accidental spills of industrial products. De Stefano et al. (2015) recognised the challenge to ensure the enforcement of existing legislation which is influenced by local economic liability. The reflection in this point is what type of legal instrument is effective to enforce legislation without affecting the economic viability of the sector. This observation also related to the issues of diffuse pollution from agricultural activities, and the struggle to manage it due to a lack of legal instruments that regulate unauthorised groundwater use.

2.3.3 Groundwater legislation tools in China

In China, groundwater represents a third of the overall freshwater resources in the country, and supplies 70% of domestic use and 40% of irrigation needs (Wang et al., 2011b). The overexploitation of groundwater has been growing with the rapid economic development of recent years, causing significant drawdowns in the water tables, depletion of groundwater resources, and land subsidence (Wang et al., 2011b). In the North China Plain, there is evidence of aggressive groundwater abstraction causing damage to engineered structures, seawater intrusion, reduction of wetlands, and a serious decrease in groundwater discharge in rivers, thus affecting river flows (Jia, 2011).

The central government of China regulates groundwater use in the country, requiring permits for the installation and operation of new wells. Groundwater users are required to report abstracted groundwater volumes and are subject to a penalty fee if they exceed their allocation limits. The permits and the enforcement of the allocation system are managed by the local water administration (Wang et al., 2011b). The institutions in control of water resources management are the Ministry of Water Resources, the Ministry of Environmental Protection, and in the case of groundwater, the Ministry of Land and Resources (Wang et al., 2011a).

The Chinese state government introduced legislation to regulate groundwater development, balancing groundwater availability and safe water quality (Qiu, 2007 cited in Wang et al., 2011a). There are several laws, regulations and standards, at state and local level, that promote a sustainable use of groundwater resources, for example, Quality standard for groundwater (1993), Technical standard for groundwater monitoring (2005), and Specification of environmental impacts on groundwater for construction projects (2004), among others (Wang et al., 2011a). The quality standard of 1993 aims to protect and regulate exploitation and pollution of groundwater while protecting people's health and promoting economic development. This standard became the main piece of legislation for management of groundwater (Wang et al., 2011b).

Among regulation responsibilities, the government oversees the exploration and monitoring of groundwater resources. There are also standards, laws and rules that address these activities, as shown in Figure 2-7. Furthermore, the legal framework includes national standards for water quality, pollution prevention and so on, and local regulations dealing with water use and issues, which can be stricter than the national regulations (Findikakis, 2011). The legal framework shows a clear assessment of specific issues at different spatial levels.

On the other hand, there are issues in the groundwater management process, identified by Jia (2011) and Wang et al. (2011a), regarding participation of water users and stakeholders; these include setting priorities between competing needs, reconciling irrigation with groundwater quality protection requirements, and providing management guidance by setting rational groundwater allocation limits. Wang et al. (2011b) recognised the need to combine the "bottom-up" with "top-down" actions under consideration, in order to develop an integrated groundwater management..

2.3.4 Groundwater legal framework and management practices in Western USA

In the USA, groundwater provided 20% of water consumed in 2000, accounting for 51% of drinking water (Jakeman et al., 2016). In the country, groundwater management and allocation issues are in the jurisdiction of the individual states, but groundwater use is monitored and regulated by local Groundwater Management Districts, governed by a Board of Directors, elected locally by eligible local landowners and water users (Findikakis & Sato, 2011). This process ensures a direct participation of stakeholders in groundwater management (Findikakis, 2011), but does not ensure good communication and consultation across the whole system. This management independence can be favourable in situations where a prompt response is needed and management measures influence directly the area where the natural resource is found.

The management approach in the USA is based on the definition of zones where there are individual assessment criteria and specific restrictions developed for the management of resources in the zone (Jakeman et al., 2016). Such criteria are based on the same general principles: set water allocation priorities and to address disputes among landowners (Jakeman et al., 2016). Water for human use and the environment is managed differently in terms of water quantity and water quality (Winter, 1998).

Groundwater in the West was traditionally treated as a common-pool resource, meaning that "the right of capture defines the right to use", as expressed by Timmons (2007). This appropriation system fails to address social changes that influence the use of water; this can slow hearing and consultation processes between water users, and does not provide an immediate response when needed (Jakeman et al., 2016). This shows a lack of adaptive management in states' water management agencies.

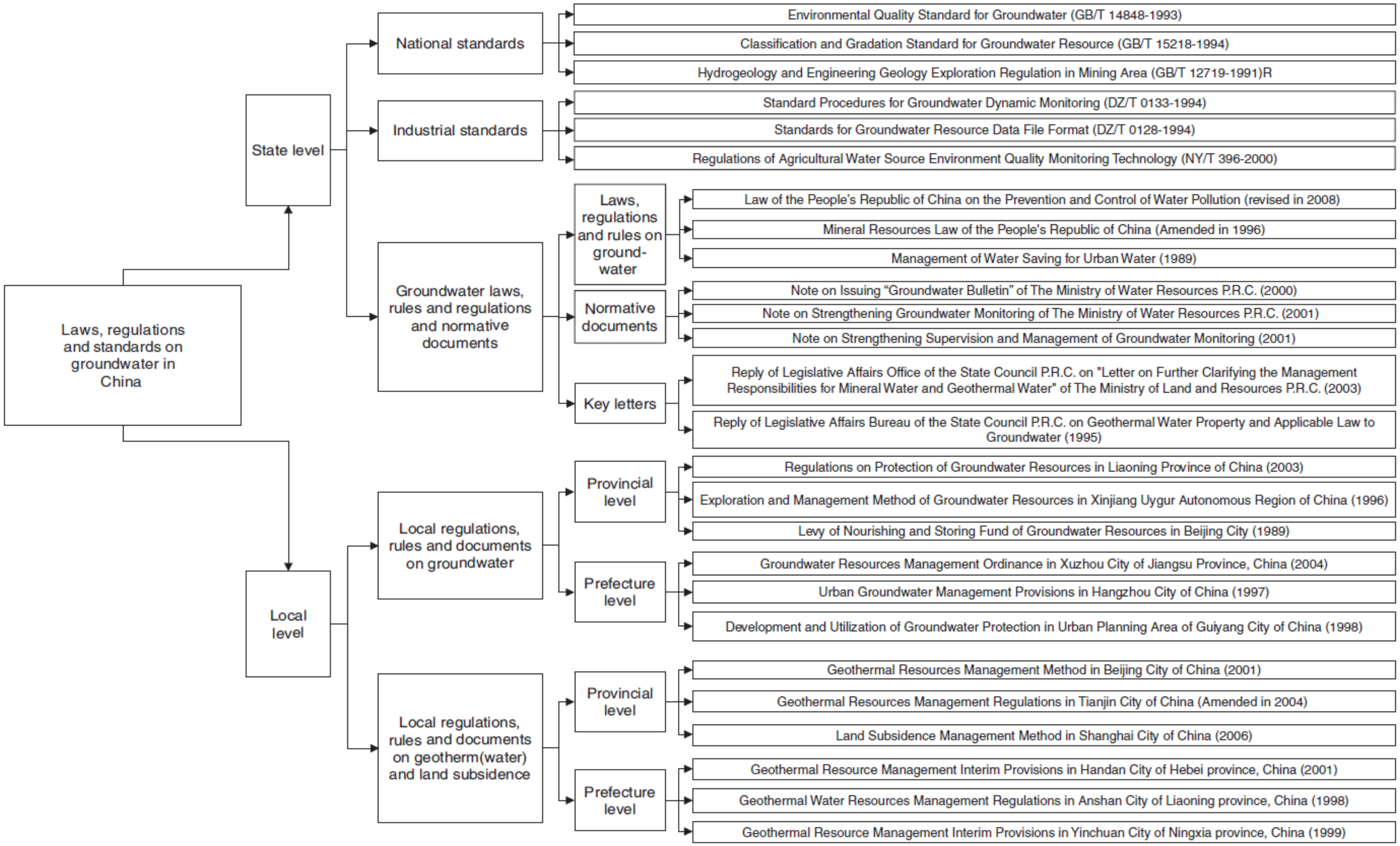

Figure 2-7 Laws, regulations and standards system related to groundwater management and pollution control in China. From Wang et al., 2011a, p. 300

Allocation and access limits are commonly established by limiting the number of well permits issued in aquifers not connected with surface water; these limits are determined by state governments (Schlager, 2006), and monitored by the National Water Quality Assessment Program; created to identify aquifers, and monitor groundwater quality. In the case of tributary (connected to other resources) groundwater resources, water users are allowed to utilise groundwater resources if they can assure authorities that exploitation will not influence instream flows or injure other water users or the environment (Jakeman et al., 2016). The positive outcome of this strategy prevents long-term over abstraction.

The assessment methodologies to develop information are subject to preferences and criteria established by districts and local authorities; in some cases a management approach can be the result of a mixture of instruments and methodologies (Sophocleous, 2010). This approach can bring positives outcomes, providing more possibilities, and options to select the most appropriate in relation to the characteristics of the area. On the negative side, the process of comparing approaches between states that share groundwater resources in a catchment will be more difficult due to the difference in methodologies, management objectives and results (Jakeman et al., 2016).

As mentioned before, integration with other districts will be challenging. It will also be important to establish a similar basis for concepts such as sustainability, safe yields, and so on, in order to avoid misunderstandings and misconceptions. Therefore, establishing objectives or management goals will be developed on a similar basis (Jakeman et al., 2016), and will recognise the necessity to integrate management responsibilities between management sectors and institutions.

2.3.5 Groundwater management framework: Australia and the Great Artesian Basin approach

Groundwater provides about 17% of the water used in Australia, and much higher percentages in some regions or during dry periods (Harrington & Cook, 2014). Groundwater use is increasing rapidly in Australia, influenced by the declining levels of surfaces resources (Jakeman et al., 2016). The Australian approach adopted a continental scale for the development of water management strategies, similar to the EU approach (Ross, 2016).

Water governance in Australia is directed by the Natural Resources Management Ministerial Council (NRMMC), which is responsible for primary industries, natural resources, environment and water policy (Clark & Brake, 2011). In 2004, the National Water Initiative (NWI) was created to establish secure water access and planning, while considering environmental and social needs. It provided an over-allocated system with sustainable abstraction rates, a framework for water markets, pricing, and methods to account for all water resources, under the framework of adaptive management (Jakeman et al., 2016).

The NWI recognises the connectivity of surface and groundwater resources and evaluates them as a single resource, but it fails to assess water quality as part of the framework (Brodie et al., 2007). States and territories have based their laws and regulations on this document which also guides the priorities for groundwater management. Even so, states have separate and different legislations and water strategies, independent of the federal government (Foster & Loucks, 2006b), providing states and territories with financial and technical support for research, planning and development.

The implementation and revision of NWI are the responsibility of the National Water Commission (NWC), which reports to the Australian government (Jakeman et al., 2016). The NWC recognised a lack of knowledge and understanding of groundwater in the country, which led to the initiative to develop the Groundwater Action Plan that will strengthen the current groundwater management approach and positively influence the current allocation approach (Harrington & Cook, 2014). Australia's system to allocate groundwater limits is defined according to long-term recharge data; extraction limits are established without compromising the integrity of the water source and the ecosystems and communities that depend on it (Jakeman et al., 2016). The management framework also contemplates measures such as restricting the use of groundwater in overexploited areas, compulsory annual allocation, and "cease to pump rules", among others. Young (2010), cited by Jakeman et al. (2016), recognises that groundwater protection is complicated, due to a current overallocation of water-use entitlements.

Despite the guidelines and principles to establish allocation limits, there are limitations to the hydrogeological characterisation of groundwater and information of the response of a groundwater system to these allocation limits, as identified by Findikakis (2011). In addition, it is recognised that the public misunderstands the state of the resource. This was the case in the Great Artesian Basin (GAB), which experienced an indiscriminate drilling of wells in the aquifer in the area during the mid-1990s (Foster & Loucks, 2006b). Currently, there are initiatives of collaborative sustainable management in the Basin; the Great Artesian Basin Bore Rehabilitation Program (1989–1999), the Great Artesian Basin Sustainability Initiative of 1999, and Strategic Management Plan for the Basin in 2000The latest programme aims to achieve sustainable use of groundwater for economic, environmental and social development (Foster & Loucks, 2006b). These strategies or local management approaches are required by the NWI to provide adequate monitoring and reporting programmes.

One of the positive results from GAB is the involvement of local landholders, industries and governments in management measures that are designed to use groundwater to sustain businesses and lifestyles, while keeping the impacts on springs and water-dependent ecosystems within acceptable limits (Clark & Brake, 2011). The implementation of NWI in states requires the active participation of water users and stakeholders in water planning and regulation; this process facilitates a mandate consultation process contemplated under the states' water legislation. Jakeman et al. (2016) highlight that the consultation process is not as efficient as government authorities believe, because it takes place after the development of plans or policies and fails to provide enough information to water users and local authorities. It is also suggested that local and regional authorities would have a more effective role in water planning and management if there were increased delegation of responsibility to these bodies.

2.3.6 Contributions from the international management approaches

Section 2.3 has provided a general overview of groundwater governance in the EU, Australia, Western USA, New Zealand, China and Saudi Arabia. Based on the information collected from studies and books that provided an analysis of these case studies, it was possible to identify strengths and weaknesses of these groundwater management approaches. The main contributions from this analysis will be discussed in the following paragraphs.

The general trend in regard to groundwater management is that central governments are devolving more groundwater management authority to regional or local organisations and providing greater transparency in the implementation of relevant legislation (Findikakis, 2011). All the case studies have recognised the importance of developing a management framework focused on the sustainable management of groundwater resources and establishing specific authorities or institutions to oversee groundwater.

Approaches such as fully integrated management of all sources of water, as intended by the WFD, is a very ambitious goal (Jakeman et al., 2016). The advantages of a strong, central direction and coordination with decentralized local management and water users are the improvement of effectiveness, enabling the process of policy implementation. In order to achieve sustainable integrated goals, it is necessary to implement the concepts of collaborative planning and adaptive management at all spatial scales. Even though shifting to the suggested approach may take various reforms and change of management views, decision makers should always consider that the approach entails great benefits, for example, stakeholder participation, social inclusion, institutional improvement, and capacity building.

The concept of stakeholder participation has been repeatedly emphasised as one of the key elements of integrated water resources management (Findikakis, 2011) and groundwater sustainability. Water users have control of the implementation of water management measures, and therefore control their effectiveness. It is necessary to develop and improve the communication process to share information with water users and create accessible ways of communicating with the authorities. Planners, impact assessors and scientists, community members and stakeholders need to communicate and plan well together, and keep what they hope to achieve at a manageable level.

Another issue identified is the lack of emphasis on groundwater management frameworks to develop sufficient and adequate technical information regarding groundwater systems. There is a need to focus efforts to better characterise and understand hydrogeological groundwater systems to develop a complete understanding of the systems and their connection to other resources and environmental variables that affect the response of groundwater systems. This will guide decision makers in the development of plans, establish management goals and monitor aquifer use, and impose restrictions on abstraction rates. Studies and field investigations, supported by numerical modelling and continuous monitoring, support the assessment of a water budget for each aquifer system and determination of the sustainable level of groundwater abstraction.

It is difficult to centrally manage groundwater monitoring because groundwater abstraction is very diffuse. On the other hand, groundwater users and local governments often have insufficient mandate or resources to put broad-scale monitoring programmes in place. Under those circumstances, engaging groundwater users in hydrological monitoring enables water users to develop an appreciation of the factors affecting the groundwater system, the performance of their wells, and water requirements for their use (Findikakis, 2011).

Besides technical information, it is necessary to gather socioeconomic information regarding water demand linked to population growth, and the economic development of industrial, commercial and agriculture sectors. Groundwater legislation reforms would have to reconsider the link between land ownership and groundwater resource ownership, the pricing of the resource, the energy pricing for pumping, and charges for the use of, and access to, the public infrastructure for irrigation, as well as market-driven options in agricultural development, and the co-dependency of city and rural areas (Findikakis, 2011). Management agendas will need to include the use of economic models to calculate the total costs and benefits of additional groundwater storage for each basin, and compare different future scenarios with and without the ability to store more groundwater for future use.

As a final analysis, the most effective sustainable management strategy for groundwater is to adopt a collaborative management approach, based on the preservation and sustainable use of groundwater resources. Centralised and integrated approaches showed more effectiveness in achieving sustainability. Management frameworks that focus efforts equally on developing technical/social/economic information, while promoting stakeholder involvement and protecting groundwater quality and quantity, are more likely to be effective.

2.4 Water resources management in Bolivia

The following section gives an overview of the current situation of water resources management in the country, emphasising the use and management of groundwater resources.

Bolivia is one of the poorest and, in many ways, the least developed country in South America. The country has been through a legislative change over the last few years, due to the political vision introduced by the current government (Spronk, 2014). The new State Constitution of 2009 emphasises the need to develop additional laws that regulate water resources rationally. These new laws should replace the outdated Water Law of 1906.

Articles 373 to 377 of the new State Constitution consider that water is a fundamental right to life and must be used in accordance with traditions and ancient customs and origins. Water resources, in all their states, including surface and groundwater, are finite, vulnerable, strategic resources and fulfil a social, cultural and environmental role ("Constitution of the Plurinational State of Bolivia," 2009).

In Bolivia, water resources are a fragile element, and this is partly because this resource is scarce in almost half the territory (Buxton et al., 2013). A quick look at national newspapers in any period of the year shows that this is a country that is plagued by droughts, hail, floods, and other climatic manifestations, which in many cases are unpredictable and further aggravated by phenomena such as El Niño (Escurra et al., 2013). The fact that the rural economy depends on water resources makes it necessary to implement management strategies at both local and national levels (Van Damme, 2002).

Bolivia has the highest rate of water availability per capita in Latin America; 88% of the population has access to a safe water source, according to the JMP (Joint Monitoring Programme). The main sources of water are rivers, streams that create lakes, lagoons, and wetlands (surface water resources), and groundwater supplies the rest of the demand. The main uses of water are agriculture (91%), consumption (7%), and industrial process (2%, including hydroelectric power generation), and, according to the Country's Constitution, water resources cannot be used for commercial purposes (NEI, 2013)

The rapid growth of the urban population (65% of the population) and certain industries have caused a high overallocation of water services, primarily surface sources that are highly sensitive to climate change and contamination (MMAyA & VRHR, 2014b). Groundwater sources are a secondary source used to satisfy demand, but exploitation of these sources is expected to increase rapidly. Groundwater sources are not clearly allocated or assessed currently in the country. Each state's public water company is in charge of the management and use of groundwater (Alcocer, 2010), but there is no legislation that regulates the exploitation of this resource.

Despite the notable increase in the coverage of drinking water services at national level, in rural areas there are many difficulties in supplying drinking water, especially due to the scattered population, the lack of municipal capacity to generate and channel projects, and the lack of investment interest of the private sector. In rural areas, in addition to having low percentages of coverage, in most cases the supply is made through public sources and not through household connections (Jiménez & Galizia, 2012).

Water management in Bolivia has always been inefficient because of a lack of policies and regulation. Most of the population does not have access to good quality water, because of the lack of investment in infrastructure and technology. Moreover, the country does not have the economic capacity to pay for scientific studies to explore in detail the physical and chemical characteristics of the water resources (Alcocer, 2010). The companies in charge have issues with infrastructure, tariff regulations, financial sustainability, and inefficient operation services (Miranda, 2016).

In Bolivia, as in other Andean countries, there is increasing competition for the multiple uses of water. Demands for agricultural, domestic and industrial use are no longer as geographically separated as before. These sectoral demands increase and overlap more and more, which causes new conflicts over water. Water is seen as a source of conflict in Bolivian society – a clear example is the so-called Water Wars of 2000 and 2006 in Cochabamba and El Alto, reflecting the difficulties the country faces in undertaking a water resources management approach that provides stability to the population (Spronk, 2014).

Climate change, water stress and environmental degradation are affecting the Bolivian population and represent major threats to human security and well-being (Escurra et al., 2013). There is a clear connection between water scarcity, food insecurity, social instability and potentially violent conflicts. In the region of La Paz, the area of study, water resources are already depleted (Luksic, 2010). Currently water consumed in the city comes from surface water sources (rainfall and glacier melting), supported by groundwater exploitation from the Purapurani Aquifer. Groundwater is used as an alternative source of water in the most remote places around the city. Dams are reaching their supply limit to meet increased demand from population growth (MMAyA & VRHR, 2014b). The influence of climate change will also affect precipitation and temperature, which will influence recharges to the groundwater aquifers. This means that water demand will also be higher and new sources of water will be needed.

In 2006, the Ministry of Water was created, and later restructured into what is today the Ministry of Environment and Water. Based on the principles that access to water is a human right, that water is not to be used for lucrative purposes, and that the state is responsible for its development and management, priority is given to the provision of drinking water to urban and rural areas through municipal governments, followed by provision of water for agriculture, and finally its sustainable management. Since 2006 surface water management has been encouraged through Integrated

Water Resources Management IWRM (GIRH in Spanish), Integrated Watershed Management IWM (MIC in Spanish) and Basin Management Plans (PDC in Spanish).

2.4.1 Occurrence of groundwater in Bolivia

Groundwater resources in Bolivia have not been efficiently regulated in relation to their exploitation and development. Currently there is no policy for sustainable use, and no information regarding the availability of the resource throughout the country (Alcocer, 2010) or their management. The Bolivian government faces the challenge of developing and disseminating information about groundwater, and promoting socially sustainable management policies.

Groundwater is not always taken into account in watershed management plans, which is strange and impractical when it is known that the highest percentage of drinking water and irrigation water in rural and urban areas comes from underground aquifers. The availability of groundwater depends on several factors, such as the nature of the rocks comprising the aquifers. It also depends on the recharge and discharge processes, among other factors (Foster & Loucks, 2006b).

The quality of groundwater is directly related to the rainfall volumes, as well as to the type and composition of the rocks where rainwater is stored or accumulated or de-iced after percolating towards them (De Vries & Simmers, 2002). The groundwater resources are contaminated by urban waste water, industry and mining activities, and citizens are not informed about the state of the groundwater bodies and how they can protect and sustainably manage them (Duwig et al., 2014). It has been recognised that the aquifers can be overexploited or contaminated due to unsustainable exploitation. Moreover, there is a lack of specialists in the subject, and insufficient finance to study the resources, their management and protection (Rivero, 2010).

There are very limited local studies and their technical information is neither organised nor systematised (Alcocer, 2010). In 1985, the Geological Service of Bolivia (GEOBOL) developed the Hydrogeological Regional Map of Bolivia, and defined five hydrogeological provinces in the country that present fundamental differences in their lithologic and structural conformation (JICA, 1987).

To date there have been five large hydrogeological units identified, with a description of the existing abundance of fresh water in each of them (Jiménez & Galizia, 2012). The zones with light blue colour represent areas of significant abundance of groundwater with differences in location and amounts. Areas with green tones shows local availability of groundwater sources, and finally brown areas represent zones with highly limited groundwater resources available.

Groundwater is mostly used for human consumption and industry and, secondarily, for irrigation. The areas of most intensive use are: La Paz, Oruro, Potosí, Cochabamba, Chuquisaca, Tarija, and Santa Cruz de la Sierra (Rebouças, 1999). To date, there is no centralised information about the quantity, quality, availability and pollution of groundwater resources in Bolivia. Occasional studies such as the study on groundwater development in rural areas in the Republic of Bolivia developed in 1996 by the Japanese International Cooperation, and the Water Resources Assessment of Bolivia study of 2004 developed by the US Army Corps of Engineers, provide an overview, yet incomplete, of this resource in the country.

The accessibility to groundwater resources in the country is limited by variations in geology and precipitation. These characteristics influence the accessibility to exploit aquifers: some areas are relatively easy to access and drilling sites are easily determined – this occurs in the area of the Andean Altiplano. The Altiplano is an arid plateau between the western range (Cordillera Occidental) and the eastern range (Cordillera Oriental) with the Titicaca Lake farther north. The quantity and quality of groundwater in the Altiplano varies from north to south. Low precipitation and high salinity contribute to poor groundwater conditions in the southern Altiplano area (US Army Corps of Engineers, 2004). The area of study and the Purapurani Aquifer are located in the Altiplano.

In one of the biggest and important cities in Bolivia, La Paz City, groundwater sources provide 20% of the water demand (MMAyA & VRHR, 2014b). The city is the government's main centre and is the most developed urban area in the country. It faces the challenge to supply the water needs of a constantly growing population. The only aquifer currently providing water is the Purapurani Aquifer, through the Tilata supply system (MMAyA & VRHR, 2014b).

These issues have been recognised under the current President Evo Morales' administration, which is currently developing an institutional and legal framework based on the inclusion of rural communities and the empowerment of indigenous communities in the management of water resources. Through the creation of institutions such as the Environment and Water Resources Ministry (MMAyA in Spanish), the Vice-Ministry of Water Resources and Irrigation (VRHR), and other regulatory institutions, the government has been developing an integrated water resources management approach by investing in hydrographic studies and developing capacities (MMAyA & VRHR, 2010).

Within the framework of these institutions and the recognised water problems, the VRHR has developed the National Basin Plan (PNC in Spanish), which establishes and promotes the implementation of participatory and sustainable policies, standards, technical tools and methodological development for an Integrated Water Resources Management System (IWRM) across the country. The PNC promotes the creation of IWRM plans known as Basin Management Plans (PDC in Spanish) in medium and large basins with complex water management issues (e.g., resources under pressure or highly significant for the development of the area) and high demographic concentration (MMAyA & VRHR, 2010).

The VRHR is currently working on the Katari Basin Master Plan (PDCK) as a baseline for the development of future PDCs throughout the country. The PDCK will integrate hydrological, geographical, socioeconomic and institutional information to establish a baseline for the basin, which will be stored and managed on a Geographical Information System (GIS) (Rivero, 2010). As one of the main hydrogeological components, the plan aims to formulate a proposal for Sustainable Management for the Purapurani Aquifer to contribute to the sustainability of the groundwater supply, both in quality and quantity. Flow modelling will be used as a tool to evaluate the system response to disturbances induced by human activity, promoting the participation of communities and the sectors involved with this resource (MMAyA & VRHR, 2010). This component is one of the first initiatives to promote sustainable use of groundwater resources in the country and build capacities.

2.4.2 Groundwater uses in the metropolitan area of La Paz (study area)

The metropolitan area of La Paz (Figure 2-8), which includes the towns of La Paz, El Alto, Viacha, Achocalla, Pucarani and Laja, has its water sources from rainfall and melting glacier ice for domestic, agricultural and industrial uses (MMAyA & VRHR, 2014b). In recent decades, the lack of management and optimisation of the water supply, and the demand on surface water and an easy access to groundwater, has led to a disproportionate increase in the exploitation of groundwater sources and a decline of the supply. Research studies of the aquifer are needed, quantifying their potential, that is, knowing the potential supply in order to address the demand for such activities, to ensure the provision of a continuous water supply.

Figure 2-8 Cities of La Paz and El Alto in Bolivia. Adapted from Mapade.org, n.d, http://www.mapade.org/bolivia.html

In the metropolitan area, groundwater has been exploited without knowledge of the different aquifers that exist and are exploited in the area. Evidence of poor management of groundwater resources is the conception of these sources as "safe" in the communities, which also increases the risk of overexploitation of aquifers (MMAyA & VRHR, 2014b).

The Purapurani Aquifer supplies water for the cities of La Paz and El Alto, one of the biggest metropolitan areas of the country. The aquifer is located at the north-eastern edge of the Altiplano and below El Alto (Figure 2-9). The area of the aquifer is 371 km^2 (MMAyA & VRHR, 2014b). Drilling and extraction of groundwater is taking place currently, but not in accordance with a planned approach. Current government directives for drilling and well constructions are not based on any data. In addition, the population near El Alto drills wells without permission. This situation compromises future availability of water in this aquifer and the region.

The Purapurani Aquifer is part of the Katari River Basin (north-east) located on the western flank of the Cordillera Real mountain range, at the north-eastern edge of the Bolivian Altiplano and below and around the city of El Alto (MMAyA & VRHR, 2014b). The delimitation was developed according to the lithological control of glaciofluvial and alluvial sediments, which form the aquifer, surrounded by glacial sediments, Quaternary (north) and Paleozoic and Paleogene rocks (west and south). The operating system area of the Purapurani Aquifer is 371 km^2 as shown in Figure 2-9 (MMAyA & VRHR, 2014a). The aquifer area exceeds the administrative boundaries of the municipalities of El Alto, Viacha, Laja and Pucarani according to the study by JICA in 1987 and 1988 (MMAyA & VRHR, 2014a).

Studies conducted by the UN in 1968–1973, JICA in 1987–1990 and the MMAyA in 2011, lack aspects such as characterisation of aquifers, evaluation and monitoring of water quantity and quality (monitoring of groundwater levels, potentiometric or physical parameters, chemical and bacteriological characteristics); pumping tests (well, aquifer, staggered, continuous, short and/or long-term); complete inventory of wells (location, filter design, operation flow) (MMAyA & VRHR, 2015)

There are a considerable number of wells that are not considered in the inventory campaign of the VRHR-PDCK in 2011; this is because most of them belong to private companies and/or individuals that do not report their existence and do not allow access to them, or they have been drilled or constructed after the inventory campaign.

Water is essential to the future of Bolivia and, therefore, water resources management must be considered as a priority. Water must contribute to Bolivia's struggle against poverty and marginalisation and effectively contribute to the sustainable development and growth of the country. Even though Bolivia ranks seventh in the world in terms of water resources, 60% of the territory is likely to become a desert area by the unsustainable use of water. In Bolivia, the water resources (surface and groundwater) are limited and fragile, due to scarcity and inefficient management.

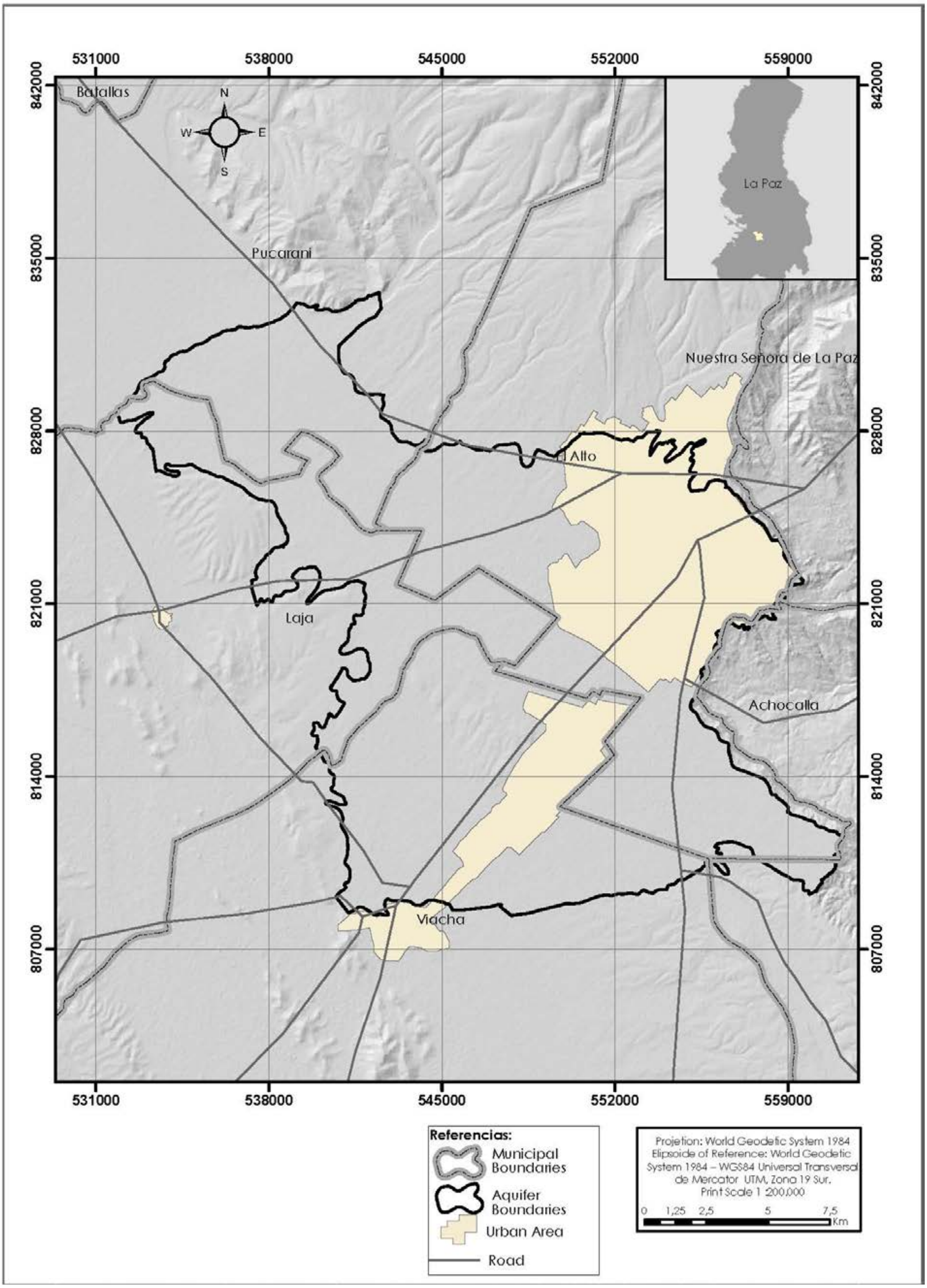

Figure 2-9 Delimitation Purapurani Aquifer. From VRHR, 2016, Annex 1

Chapter 3 Methodology

This chapter provides the details of the study strategy and the methods used to collect data. The entire study process was carefully documented and the data collected was recorded at each stage, so that the entire process can be replicated, if necessary, by other researchers. In addition, documenting the study process will also help in updating the review in the future to include additional studies that might have been carried out.

The chapter is divided into four main sections. The first section provides a literature review on the methodology essential for the development of the adaptive analysis that is the aim of this study; it also provides the fundamental concepts of the adaptive management approach: panarchy and adaptive cycles. The subsequent subsections are focused on research methods, data sources and collections, and research limitations. These subsections provide the principles with which this research was developed, as well as showing and identifying the limitations that were encountered.

3.1 Literature review on methodology

The study is grounded in the concepts of sustainability analysis and sustainable management. This approach provides a broad overview of social, economic, environmental, and cultural aspects related to the management of groundwater resources. These concepts are complementary to each other, and, when used jointly, the outcomes of this project could be highly significant. Furthermore, based on the background to the study area, this approach seems to be an innovative tool that can be successfully implemented and accepted by Bolivian society.

3.1.1 Sustainability analysis framework

The sustainability analysis framework builds on the concept of adaptive cycles from the studies of Gunderson and Holling on understanding transformations in human and natural systems (Jenkins, 2015a). The sustainability analysis framework is based on five elements:

- Adaptive cycles and nested adaptive cycles
- Failure pathways
- Critical variables and thresholds
- Management interventions and institutional arrangements

These components are described below.

Adaptive cycles and panarchy (nested adaptive systems)

The adaptive cycles help to describe biophysical (environmental) and socio-economic systems, such as groundwater systems. The framework considers interactions over these systems and allows the identification of their changes at different spatial scales (Jenkins, 2016), leading to an analysis of nested adaptive cycles or panarchy. This section will first describe the adaptive cycle.

The approach of adaptive cycles helps to understand how a system works, considering biophysical (ecosystems) and social components and their connections. This approach aims to recognise in a system the potential for change, the degree of connectedness between variables and processes, and the resilience (Gunderson & Holling, 2002). The approach characterises the change under four phases, as shown in Figure 3-1; these phases are:

- **Exploitation** ($\mathbf{r}$) – use of resources (in this case, water)
- **Accumulation** ($\mathbf{K}$) – the storage of material or energy in the system as a result of exploitation, which leads to loss of resilience
- **Release/disturbance** ($\mathbf{\Omega}$) – disturbance in the system as a result of accumulation, causing release of material or energy stored, changing the structure and function of the system
- **Reorganisation** ($\boldsymbol{\alpha}$) – restructuring of the system after disturbance; during this stage, the system may shift to a new regime or follow a recovery stage to persist in the original regime.

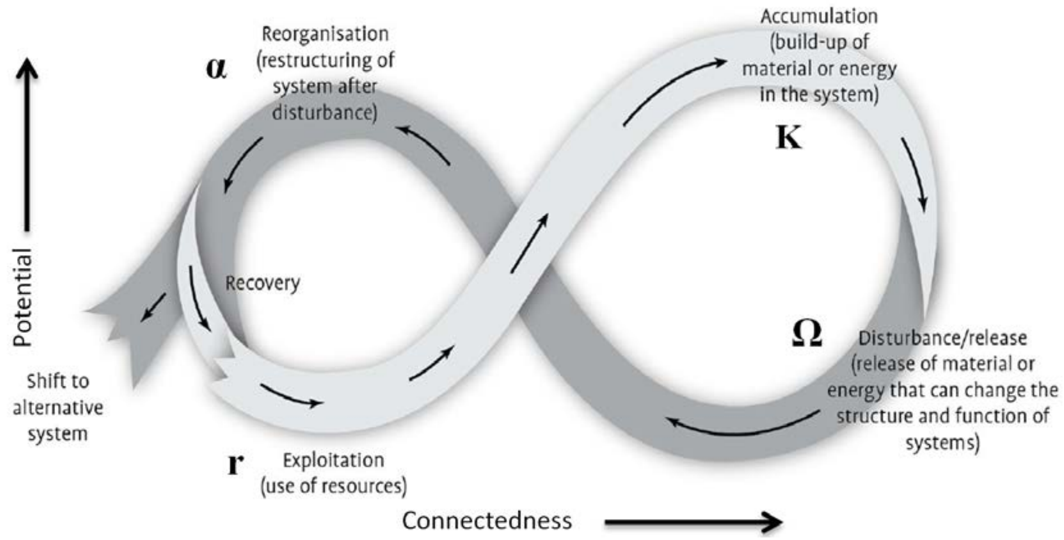

Figure 3-1 Adaptive cycle phases and key properties. Adapted from Gunderson et al. (2002)

The front loop of the cycle (changes from $\mathbf{r}$ to $\mathbf{K}$) is the slow incremental phase. Under the framework of this study, the connection between these phases can be understood as the transition of the exploitation of groundwater leading to the pressure on the resource exceeding the capacity most of the time. The back loop (from $\mathbf{\Omega}$ to $\boldsymbol{\alpha}$) represents a rapid phase of reorganisation leading to renewal or reorganisation. Related to this study, the disturbance is achieved when the exploitation rates of groundwater are exceeded or the resource has been polluted causing a change in the natural state of the resource (Allen et al., 2014). As a consequence of this disturbance, the system moves on to the reorganisation phase where management measures can be implemented; it is important to consider that this phase includes natural renewal processes. When this process does not achieve recovery to natural state, the system shifts to an alternative system.

On the other hand, if the system recovers, it shows resilience, which is the capacity of a system to absorb disturbance and still retain its basic function and structure (Angeler et al., 2015). Resilience is one of the key properties of adaptive cycles, along with potential and connectedness. The evaluation of the potential of the resource helps to identify the limits of resource for harvesting or exploitation. The potential can be assessed within the ecosystem and social characteristics, identifying knowledge, technology, and skills that are available for change in the system (Holling & Gunderson, 2002). The property of connectedness addresses the nature and degree of links between processes; it recognises the strength of the connections that mediate and regulate the influence between inside processes and the outside world. Assessing the cycle stages and their properties helps to identify uncertainties and limitations that may arise in future conditions of the environment or towards meeting management goals or objectives.

The development of the adaptive cycles in this study will help to identify management approaches and decisions based on the concepts of resilience, vulnerability and adaptive capacity (Pahl-Wostl et al., 2007) of the system (Purapurani Aquifer). The assessment of adaptive cycles will provide a new perspective on the information related to the response of the system to current conditions, future stressors, management decisions and policy implementation within the Bolivian framework. This approach will lead to the development of a sustainability analysis of the Purapurani Aquifer and future groundwater resources in Bolivia.

While the concept of sustainable management of adaptive cycles was originally developed for natural resource management, the concept is being used more widely for management of transformations in both human and natural systems (Jenkins, 2015a). Four types of sustainability issues have been recognised (Jenkins, 2015a), as shown in Figure 3-2:

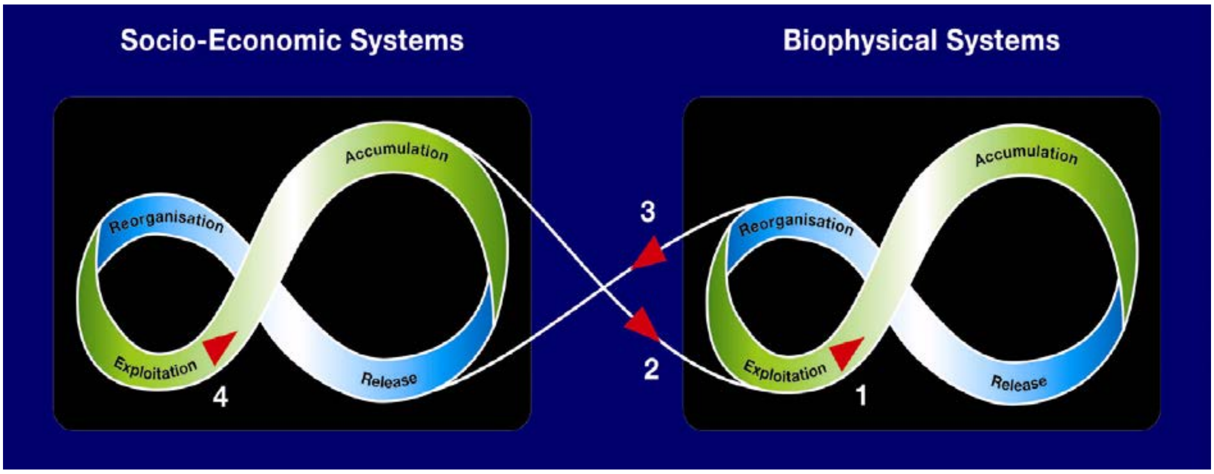

Figure 3-2 Type of sustainability issues, from Jenkins, 2015a, p.25

Type 1, represents the issues regarding the capacity of a natural system to adapt to demands made upon a socio-economic system (SES), type 2 represents the capacity of the linkages of the SES to the biophysical systems (BPS). The following types, 3 and 4, show the capacity of the linkages of the BPS to SES, and finally the capacity of the SES to be maintained. This approach guided the identification of issues in the Purapurani Aquifer in relation to promoting a sustainable management.

The adaptive cycles also identify processes that operate at different spatial scales or hierarchy levels (top-down sequence). The conceptual linkages between these cycles are known as a nested set of adaptive cycles, also referred to as a panarchy. A panarchy is a conceptual model that describes the ways in which complex systems of people and nature are dynamically organised and structured across scales of space and time (Allen et al., 2014; Gunderson & Holling, 2002; Holling & Gunderson, 2002).

The model recognises the connections between cross-scale levels and their influence from lower levels to the next higher, or vice versa as shown in Figure 3-3. There are multiple connections between the levels and phases, but Holling and Gunderson (2002) recognise two significant connections in order to achieve sustainability – these phases are named “Remember” and “Revolt” as identified in Figure 3-3. This changes the concept of hierarchy from fixed static structures to dynamic adaptive entities, whose levels are sensitive to small disturbances at the transition from growth to collapse (the Ω phase) and the transition from reorganisation to rapid growth (the α phase) (Holling & Gunderson, 2002).

Panarchy provides a perspective to understand ecosystems, linked to social–ecological systems and governance (Holling & Gunderson, 2002). Chapin et al. (2009) suggest that "we must understand the world, region, or community as a social–ecological system" (p. 22) in which people depend on resources and services provided by ecosystems, and ecosystem dynamics are influenced by human activities. Adopting this perception, and analysing systems as social–ecological reflects the interactions of physical, ecological, social processes (Chapin et al., 2009) and institutional arrangements for its management (Pandey et al., 2011). Moreover, it summarises the concept of sustainability.

The conceptual linkages between system attributes processes and resilience have made the adaptive cycle a valuable tool in the analysis and management of social and ecological systems in the current period of rapid environmental and social–ecological change. The use of nested adaptive cycles in this study will help to identify critical variables, thresholds, opportunities and transformations in the Purapurani Aquifer system, in order to provide sustainable management interventions. The study will analyse the social–ecological systems (SES) of the Aquifer and the interaction with internal and external factors. Moreover it will identify management intervention points where a transformation may most easily be implemented (Allen et al., 2014), based on socio-economic arrangements and collaborative governance linked to the biophysical system (BPS). The identification of the scales and structures in the Purapurani Aquifer through the adaptive cycles will help to develop an understanding of the framework of the groundwater system and its relationship with the social and legal characteristics of the study area. The results of this analysis will be discussed in Chapter 5 of this study.

Failure Pathways

"Failure pathways are the processes that have the potential to cause system failure and shift the system to an alternative degraded state" (Jenkins, 2015a, p. 11). These help to identify issues that create vulnerability regarding each system and the connections within BPS and SES and spatial scales. The failure pathways shown in Figure 3-4 were identified by Jenkins, as guidance for its application as a component of the sustainability analysis. It can predict in advance the issues that need to be addressed and for which limits need to be set, such as the need to develop a sustainability strategy.

The failure pathways identified in Figure 3-4 can be related to the sustainability issues identified before; Table 3-1 shows this relationship. Issues such as climate variability, local natural resource depletion and local environmental degradation were recognised in many case studies developed by Jenkins, such as the collapse of the Maya, Waimakariri catchment, and in many of his lectures I attended. These issues were helpful for this study.

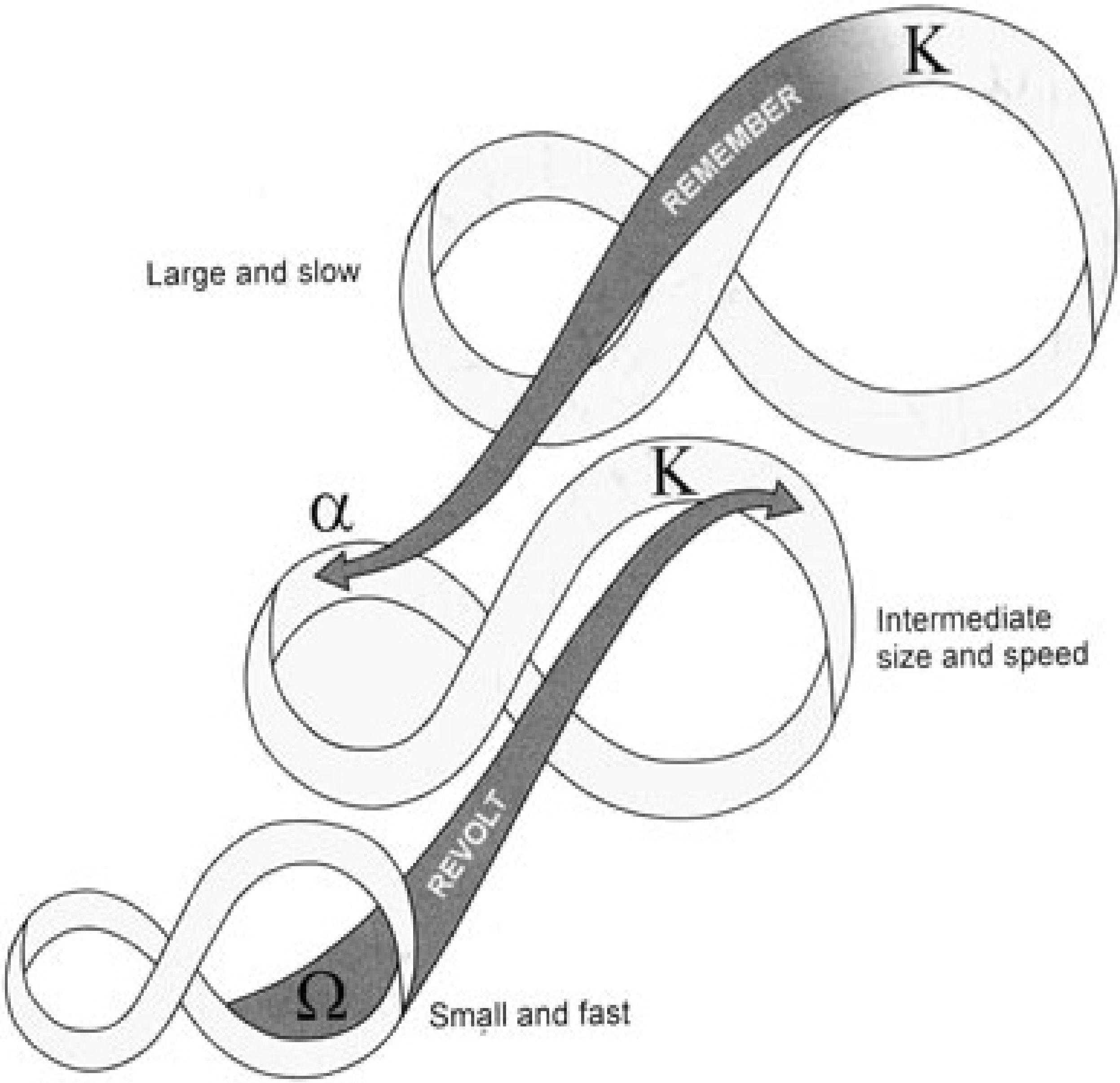

Figure 3-3 Panarchy or nested adaptive cycles. From Holling & Gunderson, 2002 p. 75

Note. Three selected levels of a panarchy are illustrated, to emphasise the two connections that are critical in creating and sustaining adaptive capability. One is the "revolt" connection, which can cause a critical change in one cycle to cascade up to a vulnerable stage in a larger and slower one. The other is the "remember" connection, which facilitates renewal by drawing on the potential that has been accumulated and stored in a larger, slower cycle. The number of levels in a panarchy varies, is usually rather small, and corresponds to levels of scale present in a system.

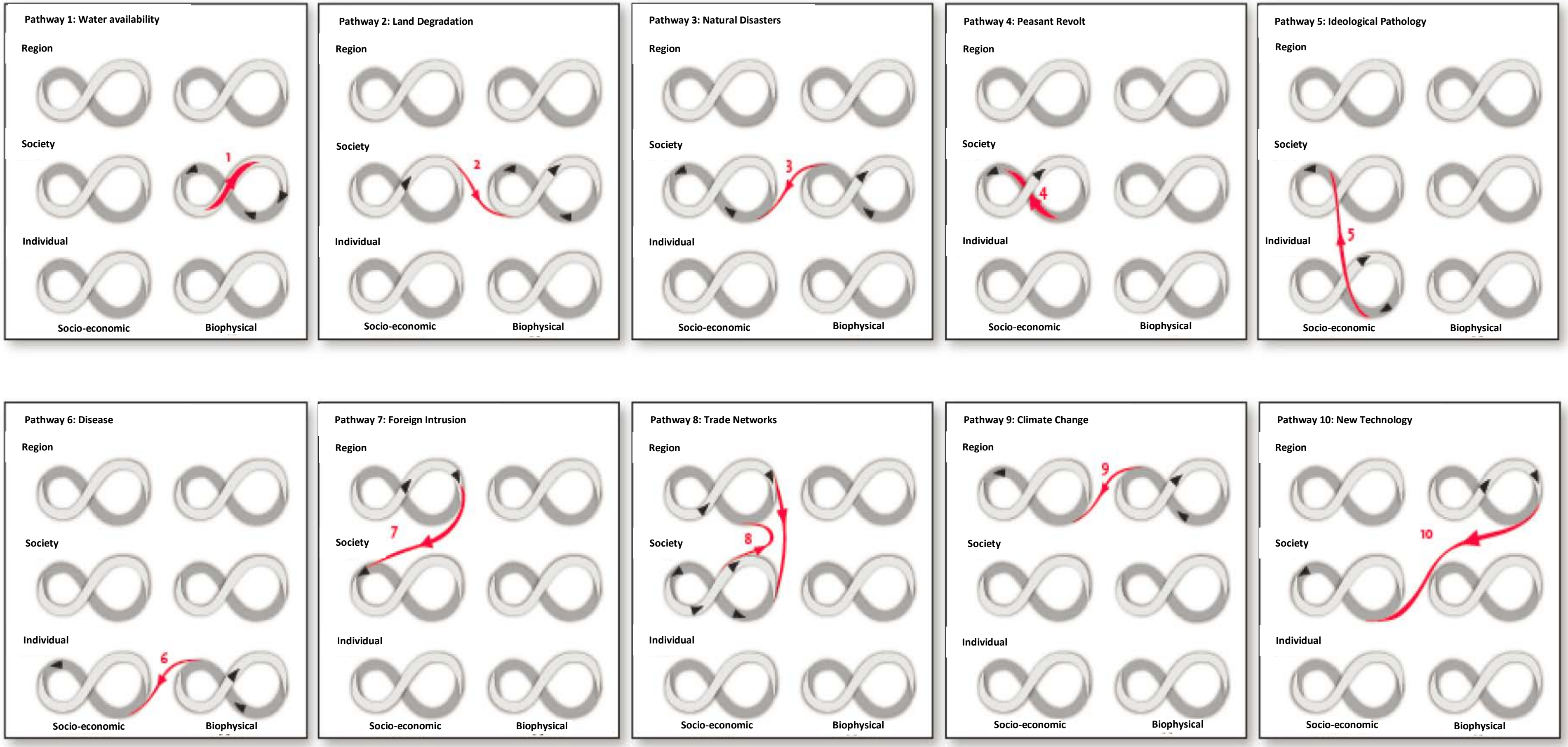

Figure 3-4 Failure pathways. From Jenkins, 2015a, p. 29

Table 3-1 Failure pathways classification

GEOGRAPHIC SCALE	TYPE OF SUSTAINABILITY ISSUE			
	TYPE 1 Biophysical maintenance	TYPE 2 Socio-economic impact on biophysical	TYPE 3 Biophysical impact on socio- economic	TYPE 4 Socio-economic maintenance
Region	*Climate Variability*	9. Climate change	10. New technology	7. External intrusion 8. Collapse of trade networks
Society	1.Water availability	2. Impact of water use	3. Natural disasters	4. Institutional Arrangements
Individual	*Local natural resource depletion*	*Local environmental degradation*	6. Disease	5.Individual commitment

Note. Adapted from Jenkins, 2015a, p. 29

It is important to highlight that these categorisations are guidelines for the identification of failure pathways. In the implementation of this approach for the Purapurani Aquifer, the titles of these pathways were adapted to suit the characteristics of the area and provide a comprehensive analysis.

Critical variables and thresholds

"For sustainability analysis, critical variables and their thresholds provide the basis for defining management interventions to address sustainability issues… " (Jenkins, 2016, p. 11). Critical variables and thresholds are the next steps for the sustainability analysis. The critical variables are measures that characterise the processes on failure pathways, and thresholds are values that points out the change of state of the critical variable.

In the case of water resources management, it can be exemplified as water quality and a threshold as concentration of a certain contaminant in water bodies. These can be compared to national or international standards of water quality as the World Health Organization (WHO). Conclusively, critical variables and thresholds ensure sustainability for management interventions supported by institutional arrangements and other available management tools (Jenkins, 2015c).

Management interventions and institutional arrangements

After identifying critical variables and thresholds, it is possible to target potential management interventions and institutional arrangements to achieve a sustainable management of a natural resource. Management interventions can be categorised under three main outcomes (Chapin et al. 2009). The first is that no action (or inadequate action) is taken, leading to a degraded natural resource system. A second is that appropriate action is taken to ensure that the thresholds are not exceeded and the natural resource system retains its structure and function. The third is where action is taken to transform the system to an alternative state that has a sustainable structure and function (Jenkins, 2016). Management interventions in this study will be develop based on the third category.

Management interventions in the biophysical system of water resources can occur at each of the phases of the biophysical adaptive cycle, as can be seen in Figure 3-5. In the exploitation phase, it is reducing pressure on the resource ("reducing vulnerability"). In the accumulation phase, it is addressing legacy issues of accumulated changes in the past. In the disturbance/release phase, it is increasing resilience of systems to accommodate disturbance ("increasing resilience"). Finally in the reorganisation phase it is rehabilitating adverse effects of the system ("enhance transformability") (Jenkins, 2016).

It is also necessary to identify management interventions in the socio-economic framework to ensure the implementation of management interventions in the BPS cycle. The management interventions at the level of SES cycles can be identified for each phase: firstly, the use of human and economic resources for stakeholder, cultural and community engagement (i.e. exploitation phase); secondly, the accumulation of knowledge, social, cultural and economic capital to develop integrated approaches to sustainable strategies (i.e. accumulation phase); thirdly, the formulation of new approaches to water management that change existing practices (i.e. disturbance/release phase); and fourthly, the development of new institutional arrangements to implement the new approaches to water management (i.e. reorganisation phase) (Jenkins, 2016).

The linking of the socio-economic system and the biophysical system provides an overall framework for management intervention pathways to achieve sustainability (Figure 3-5).

Following on from this, it is also necessary to identify institutional arrangement necessary for the implementation of management interventions. Jenkins (2016) categorises these arrangements into four categories: to establish organisational arrangements to manage implementation; to develop an implementation programme; to establish and operate delivery mechanisms for the implementation programme; and to monitor the delivery and outcomes achieved.

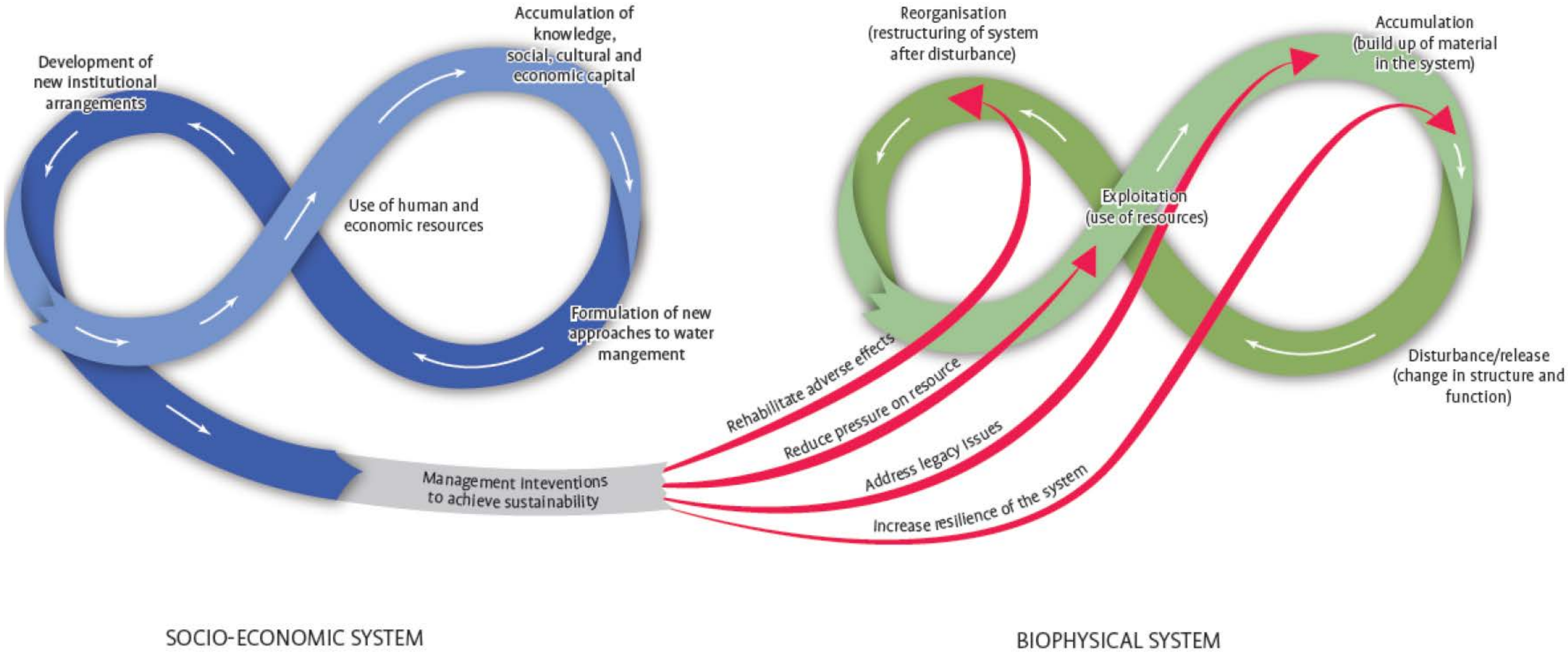

Figure 3-5 Management interventions. From Jenkins, 2015, p. 6

3.2 Research methodology and strategy

This study has an investigative character, focused on understanding the information available and analysing its relevance, which are the characteristics of qualitative research identified by Merriam (2014). The nature of the study is descriptive; according to Biggam (2011) this study is not required to answer cause-or-effect questions, but aims to capture a comprehensive knowledge in order to gain a deeper understanding of a certain topic.

The final product of this study will be descriptive and informative, and is intended to be shared with stakeholders and the community. It does not have a previously determined hypothesis, because it is not intended to predict future behaviour. The study intends to suggest interventions for management of groundwater resources in Bolivia. By gathering and analysing information from international policies and management experiences, its aim is to provide management guidance. The study is relevant to organisations (research, consulting, training, and so on) that work in policy, governance and related areas. It is also relevant for policymakers in government, in international agencies such as BID, and civil society organisations.

The study reflects the use of the concept of "Action" research design described by Walliman (2011, p. 13), as it will deal with a specific problem (groundwater management) in a particular situation (Purapurani Aquifer), while developing an understanding of its framework. The conclusions and recommendations from the findings are meant to be applied by the institutions responsible for groundwater management in the Purapurani Aquifer and the country.

The primary instrument for this study is the collection and analysis of available data through nonverbal sources such as documents on the internet, books, articles, reports, government reports, laws and statutes. Guthrie (2010, p. 99) states that the available data is particularly useful when the main goal is to persuade decision makers to use our findings: "success is more likely if we use the type of information with which they are familiar". As a secondary source of data, the study will consider the use of an unstructured interview method that consists of open-ended questions, which are subject to flexibility during the interview (Guthrie, 2010, p. 119). The interviews can go into a topic in depth and facilitate the development of the interview; there are no restrictions in content or style (Walliman, 2011, p. 98). The audio of the interviews will be recorded for further analysis and consideration while in the write-up stage of this study; notes taken in the interviews will also be considered as a collection technique.

The project will be developed in three phases, as shown in Fig. 3-6.

3.3 Data sources and collection

This study, as a systematic review, intended to collect background information from international experiences and management approaches related to groundwater resources, and current information available for Bolivian water resources management, identified in Figure 3-6 as part of Stage A, specifically points A1 and A2. This data was collected via website search, electronic databases, and direct correspondence with authorities directly involved with the management of the Purapurani Aquifer in Bolivia.

A. Collect information

- **A1.** Collect background information from international experiences and management approaches related to groundwater resources.
- **A2**. Collect current information (beginning stages of the study) to understand current socioeconomic aspects, aquifer characterisation, and institutional arrangements.
- **A3.** Generate information regarding the current use and management perceptions of the authorities, stakeholders and community representatives to develop an overview of the current situation of the Purapurani Aquifer through interviews.

B. Results analysis

- **B1.** Compile and analyse the information collected regarding the socioecological system of the Purapurani Aquifer.
- **B2**. Identify uncertainties and limitations of the information.
- **B3.** Develop the adaptive cycles for the Aquifer.

C. Adaptive analysis

- **C1.** Develop a nested adaptive cycle for the management of the Purapurani Aquifer.
- **C2**. Identify critical variables and immediate actions that need to be taken to promote sustainable management of the Aquifer.
- **C3.** Suggest management interventions for sustainable management of groundwater resources in the Purapurani Aquifer.

Figure 3-6 Research strategy and analysis framework

As a second source of data, the study carried out interviews with authorities, stakeholders and community representatives to develop an overview of the current management situation of the Purapurani Aquifer. For this objective, it was necessary to do a field trip from June 13 to August 10 of 2016. The lists of participants in the study are described in Figure 3-7, as are the criteria for selecting or excluding participants. The study used the collection method of "Observation" through field trip visits to well-monitoring points along the Aquifer in combination with other collection tools. This method helped me to observe roles and learn from others' professional experience (Guthrie, 2010, p. 108). The role employed in this research was as a "Nonparticipant", which required the researcher to be present, but not to participate in group activities. According to Guthrie (2010) this method is more productive at the time of collecting data; it allows the researcher to "focus fully on the participants and avoid distractions from the role" (p, 109).

The information retrieved from these sources helped to establish a theoretical framework of the Aquifer, and served as a baseline to establish a sustainability analysis for the Aquifer. It also helped to identify critical variables and limitations for the management and use of groundwater in the study area.

Most of the data and information collected in Bolivia was translated from Spanish to English, as were the discussions and other sources of information.

Website search and electronic databases

Websites and electronic databases were searched because they would potentially have various unpublished studies and evaluation reports related to the topic of the study. Many of the studies and reports were selected after a simple quality-assurance process. This process was based on identifying that the studies' sources were published in reputable peer-reviewed journals, or the studies were conducted by reputable organisations. Two main sources were used for retrieving information: Google Scholar and the Electronic Database/Library from the University of Canterbury.

The studies and reports cited in this study were chosen on the basis of similarities and features related to groundwater management, such as sectors analysed; type of planning adopted; outcomes and indicators analysed; methods used to analyse data, observations, conclusions; and the overall assessment of studies or report findings relevant to the review. This helped to achieve a broad characterisation and overview of the referenced studies.

Direct correspondence

The study collected information from the Vice-Ministry of Water Resources and Irrigation (VRHR) in the development of the Katari Basin Management Plan (PDCK), and other sources to build a complete framework and centralise all the information about the Purapurani Aquifer; this has been identified as essential in the Report of Sustainable Use of Surface and Groundwater Sources developed by Ministry of Environment and Water (MMAyA) as part of the PDCK.

The various reports of studies conducted by both state and private entities are scattered in offices and libraries of various state institution offices and private libraries (many of them are missing and some lost forever), and finally held by consulting firms and private consultants (MMAyA & VRHR, 2014a). These sources were considered as primary data thought to be representative in the study. As stated by Walliman (2011, p. 70), "primary data can provide information about virtually any facet of our life and surroundings"; without it, it will be difficult to have a complete conceptualisation of the matter.

Interviews

Groundwater management perceptions regarding the Purapurani Aquifer were collected and analysed, and their relevance discussed with authorities, and staff from the public and private sectors, NGOs, municipal governments and community representatives, while identifying key aspects of management issues and developing mechanisms to manage them. This information was retrieved from discussions and unstructured interviews carried out during the field trip in Bolivia. This data collection method was selected based on the understanding of the complex interaction between users and groundwater systems. Assessing the sustainability of a water system choice in a particular community requires data about user preferences and decision-making behaviour in regard to water, as well as the construction, operation, maintenance, and demolition characteristics of the system within its environmental space (S. A. Jones et al., 2013).

The criteria for selecting or excluding participants were based on the role played by each of them in the development of the PDCK and the characterisation of the Aquifer. The level of knowledge on the subject has also been considered – it is important to have informed opinions as a result of the discussions with the participants. The recruitment of participants was done through the VRHR connections with private consultants and community representatives, as shown in Figure 3-7. The participants in this study were categorised into four main groups, previously mentioned. On Phase 0 of the PDCK, the Ministry conducted interviews and focus group discussions to collect information; therefore, the study did not require semi-structured interviews or surveys. The study considered the experience and information gathered by the authorities in this matter.

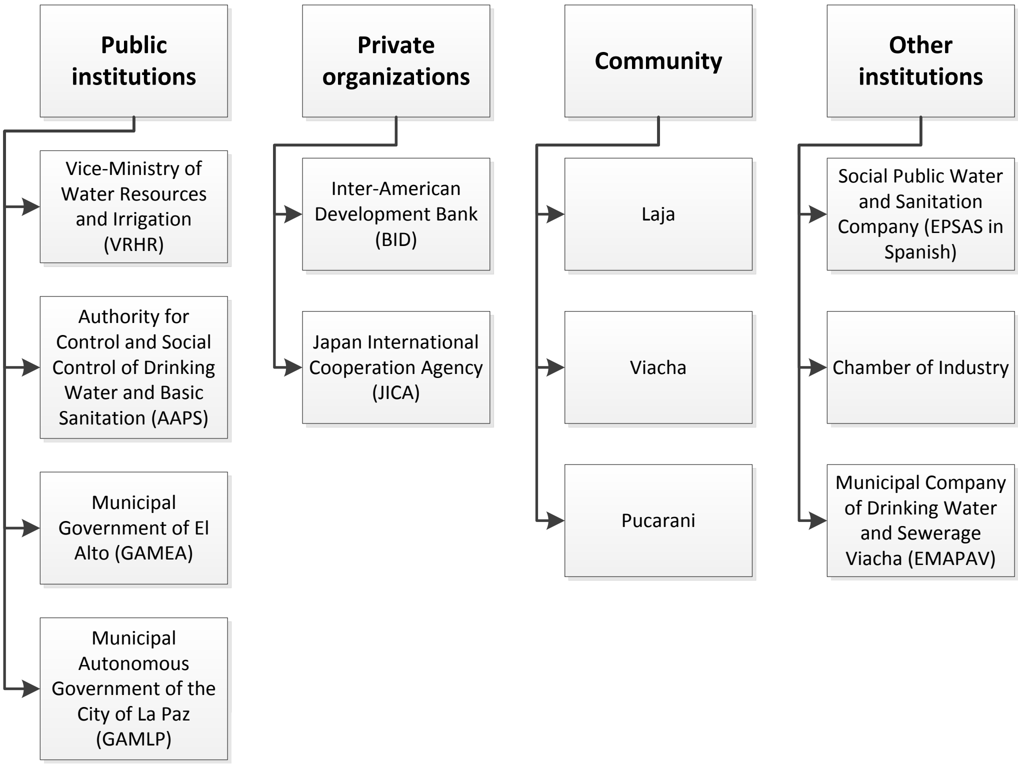

Figure 3-7 Participants of the study

The names of the participants contacted from the community were suggested by the VRHR authorities, which already had contact with them. The representatives were aware of the PDCK and had knowledge of the subject; this avoided misunderstandings in the topic and there was no need to introduce “new” information at the time of the interviews. The chosen participants gave informed opinions at the time of the unstructured interviews, based on their background and knowledge of the matter.

The topics considered in the interviews were:

a) perceptions of the current management of the groundwater resources in Bolivia, and specifically in the Purapurani Aquifer
b) expectations for future use of groundwater resources in the country and the Aquifer
c) current management tools’ effectiveness, and issues and policy deficiencies
d) effects of current use and contamination of groundwater resources in Bolivia and the Purapurani Aquifer
e) suggestions in the design of a sustainable management policy that will be achievable
f) compromises that can be taken by the authorities and the community to achieve a sustainable management of groundwater resources

g) mechanisms of data collection, technology, and professional deficiencies and experience in the characterisation of the Purapurani Aquifer.

The study involved the recording of audio in the development of unstructured interviews and note taking. The purpose of the recordings was to avoid information losses in moments when the participants expressed their opinions and the discussion took place. All the participants were notified at the beginning of the interviews of the recording procedures and the extent of the nature of the recording was explained. The recording only proceeded with the verbal and written consent of the participants. The information sheet and written consents are provided in Appendix A.

3.4 Research limitations

As with every study, this dissertation had limitations, discussed below.

I. Reluctance on the part of stakeholders and decision makers to answer to meeting requests and provide information through interviews.

Out of the 12 participants previously identified, I was not able to contact the Social Public Water and Sanitation Company (EPSAS). Despite multiple efforts to contact this institution, there was no response. A reasonable amount of time (one month) was given after the first contact with the institution (delivered letter of request of interview) until the time to leave Bolivia. I attempted to overcome this problem by reaching out to this institution through other mechanisms (email and phone calls).

The information meant to be provided by this institution was substituted for by a study provided by the Autonomous Government of La Paz (GAMLP) that addresses the responsibilities and roles of this institution in the management of the Purapurani Aquifer – the Metropolitan Master Plan for Drinking Water and Sanitation for La Paz–El Alto, Bolivia. I hoped that the broad scheme for identifying stakeholders, beginning with those with whom I have already established relationships, would minimise this problem. Field work always presents logistical challenges, including problems and delays in obtaining information.

II. Data limitations

At the initial stage of the study, there was limited availability of data regarding groundwater resources in Bolivia, and especially the Purapurani Aquifer. The establishment of the framework basis was delayed due to the lack of this information, as well as difficulty in identifying institutions involved in the management of groundwater resources in Bolivia. This did not impact the selection process of the participants before the field trip to the country.

III. Difficulty encountered with research subjects

It is necessary to consider that the answers may change due to timing and maintaining contact with the participants. Another issue is the change of authorities, responsibilities or roles – this may occur due to the end of a political mandate or for personal reasons. That is why it is crucial to recognise that the views and perspectives shown in this study are time dependent and are subject to change.

Chapter 4 Results: Analysis Framework

This chapter is structured in three main sections. The first section aims to compile and illustrate all the hydrogeological information regarding the Purapurani aquifer, this section shows the results of the compilation of three main studies gathered over the field research in Bolivia. It also provides a final analysis of the hydrogeological information, its relevance and significance.

The second section presents all the information gathered regarding the socio-economic and legal aspects influenced and connected to the Purapurani aquifer as essential part of an adaptive analysis.

Finally, the third section compiles and analyses the information collected over the interviews developed in the field research.

4.1 Hydrogeological characterisation of the Purapurani Aquifer

The primary focus on groundwater management is within its system, but as previously analysed, it also integrates linkages with many elements and factors from the environment that are related and connected. As a result, it is needed to provide a broader view to groundwater within the hydrologic cycle.

Hydrogeological characterisation provides information regarding the quantity and quality of groundwater within an aquifer, as well as the potential impacts of various stressors associated with, for example, extraction. Hydrogeological characterisation provides the scientific basis for the development of a policy for sustainable use of groundwater resources, and the identification of contingency and compensation mechanisms for prompt response to future drawdowns (Foster & Loucks, 2006b).

4.1.1 Preliminary studies

Information from three main studies related to the Purapurani aquifer was gathered and compiled. These studies are summarised in Table 4-1. A further report detailing the first groundwater study in the region, which was carried out by the Geological Service of Bolivia, could not be sourced. That report concluded that the area has a high feasibility of groundwater development (JICA, 1987).

Table 4-1 Published studies relating to the Purapurani Aquifer

Study Name	Organisation	Year	Characteristics	Limitations	Outcomes
S1. Final report for the Groundwater Development Project on El Alto District in La Paz City	Japanese International Cooperation (JICA)	1987	- Goal of the study was to ascertain whether groundwater in this aquifer could satisfy the growing demand of water in El Alto. - Groundwater balance developed.	- Limited available data. - No sustainability criteria considered. - No participation of stakeholders or the community.	- Identification of exploitation area. - First field surveys, data collection and development plan. - Preliminary assessment of water quality in the area of preferable use. - Primary water balance. - Well inventory developed.
S2. Special Report: Sustainable use of sources of surface and groundwater supplies	International Consulting Consortium under the administration of the Ministry of Environment and Water (MMAyA)	2014	- Objective was to define the best strategy for the development and expansion of drinking water and sanitation services until 2036 in the study area. - Study developed as part of the Metropolitan Master Plan for Drinking Water and Sanitation La Paz–El Alto (PMMAPS). - Compiles and analyses mostly information regarding the Tilata supply system operating in the aquifer.	- Limited qualitative and quantitative information of the aquifer. - Conclusions and recommendations based on a partial understanding of the system. - No participation of stakeholders or the community.	- Hydrogeological and technical evaluation of the current use of Tilata supply system. - Identification of studies developed in the area (past and future). - Estimation of the storage potential of the aquifer.
S3.Characterisation of the Purapurani aquifer for the development of a proposal for Sustainable Management	Vice-Ministry of Water Resources and Irrigation (VRHR)	2016	- Objective is to formulate a proposal for the management of the Purapurani Aquifer. - Study as part of the hydrogeological component of the PDCK. - Developed new qualitative and quantitative information for a broader understanding of the aquifer. - Relatively “updated” information (data from 2011). - Considered 50 wells for water monitoring and inventoried 353 wells.	- Considerable number of wells not part of inventory campaign of the VRHR-PDCK in 2011. - Failed to provide a water balance and identify the potential of the aquifer. - No participation of stakeholders or the community.	- First proposal for Sustainable management of the aquifer. - Draft of a management plan for the aquifer. - Technical information generated, with an integrated approach applying hydrogeological, isotopic, hydrogeochemical techniques. - Assessment of the degree of vulnerability of the aquifer to contamination.

The following sections provide a compilation of the information from the studies mentioned above. The sections are organised based on the usual components of a typical hydrogeological characterisation. With the purpose of providing a comprehensive document, the characterisation components are organised in two main subsections: Quantity and Quality followed by a concluding section that analyses the hydrogeological information provided in terms of a water balance.

4.1.2 Study area

The Purapurani aquifer is part of the Katari River Basin located on the western flank of the Cordillera Real mountain range, at the north-eastern edge of the Bolivian Altiplano, and below and around the city of El Alto (VRHR, 2016) .The Katari Basin, shown in Figure 4-1, is formed by three water systems. In the sector of El Alto, the Seque and Seco rivers flow into the Pallina River near the town of Viacha. The Pallina River flows into the Katari River, which reaches the Lake Titicaca through the Bay of Cohana.

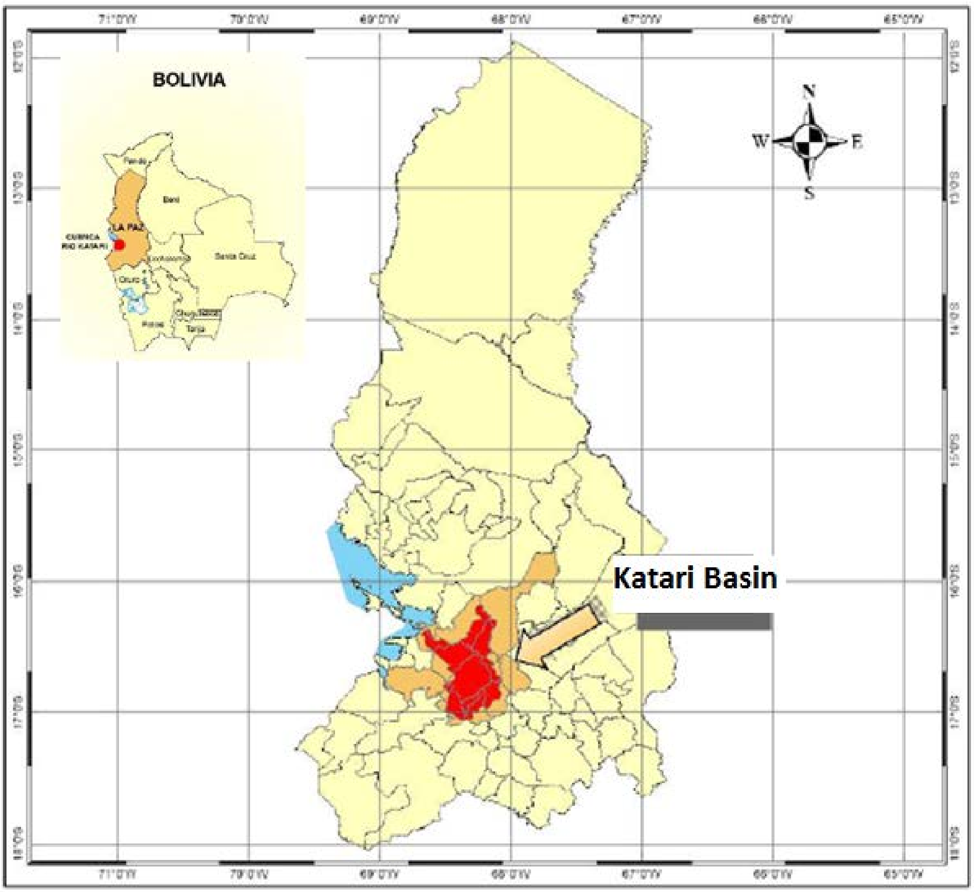

Figure 4-1 Location of the Katari Basin/ Purapurani aquifer, from BID, 2016, p. 12

Despite the abundance of water in the Katari River Basin, the surface water quality is poor. The poor water quality is due to intensive use, leakage of domestic and industrial wastewaters that are not totally treated, or have insufficient treatment, clandestine tributaries of industrial and mining, and the accumulation of fertiliser in the rural area that flow downstream (Ministry of Environment and

Water, 2010). Both domestic and industrial sewage collected by the sewer network in the municipality of El Alto are treated in the Puchukollo Wastewater Treatment Plant (WWTP), located in the municipality of Laja; discharges to Seco River then the Katari River, which finally discharge into Lake Titicaca, causing high levels of contamination (BID, 2016).

The Purapurani Aquifer is located in the metropolitan area of La Paz, which includes the towns of La Paz, El Alto, Viacha, Pucarani and Laja. The area's water resources come from rainfall and glacier melting, and are used for domestic, agricultural and industrial uses. In recent decades, the lack of a management, optimisation of the water supply and demand of surface water and an easy access to groundwater, has led to a disproportionate increase in the exploitation of groundwater sources and a detriment to the supply.

The area of the Purapurani Aquifer is 370 km^2 with an average saturated thickness of 55 m, specific porosity of 15% and 2.5 hm^3 of water stored. The aquifer extends across the administrative boundaries of the municipalities of El Alto, Viacha, Laja and Pucarani, as shown in Figure 2-13 of this study (JICA, 1987).

The aquifer has been exploited since 1989 through the Tilata water supply system and artesian wells. In 1986, JICA developed a groundwater development project for the area in response to the rapid expansion of the south-western part of the city of El Alto, hillsides in La Paz and rural communities nearby (JICA, 1987). The JICA study recognised that the water supply in 1986 was already affected by fluctuation of rainfall, climate change and water storage, and, moreover, did not cover the growing demand.

By 2012, the Aquifer supplied 20% of the water demands in the city of El Alto and a percentage unaccounted for in parts of La Paz and surrounding rural areas. The aquifer is exploited by municipal wells (Tilata system), private wells and spring catchments on the west side of the city of La Paz (MMAyA & VRHR, 2014; MMAyA & VRHR, 2015). The exploitation of the aquifer is done in an unsystematic way, where public entities such as the government and municipalities, along with private NGOs, only focus efforts on drilling and construction of wells, without considering sustainability criteria. Currently, the aquifer is the main source of water for human, industrial and agricultural consumption for the city of La Paz (West Hills) and El Alto, and the communities of Viacha, Pucarani and Laja (MMAyA & VRHR, 2015).

There are records of more than 250 wells drilled and built in the aquifer system, of which about 130 have been identified as operational, the rest are not operational or were not identified in field studies. There are an unknown number of private wells, estimated to exceed one hundred (MMAyA & VRHR, 2014b), that have not yet been inventoried.

As shown in Figure 4-2, the natural boundaries of the Purapurani aquifer, flow boundaries and boundary conditions are:

- The eastern edge of the Purapurani aquifer (Achocalla slope) is the boundary of the Altiplano. Therefore, the groundwater flow cannot continue in this direction; likewise, the slope in this zone helps to define a non-flow boundary.

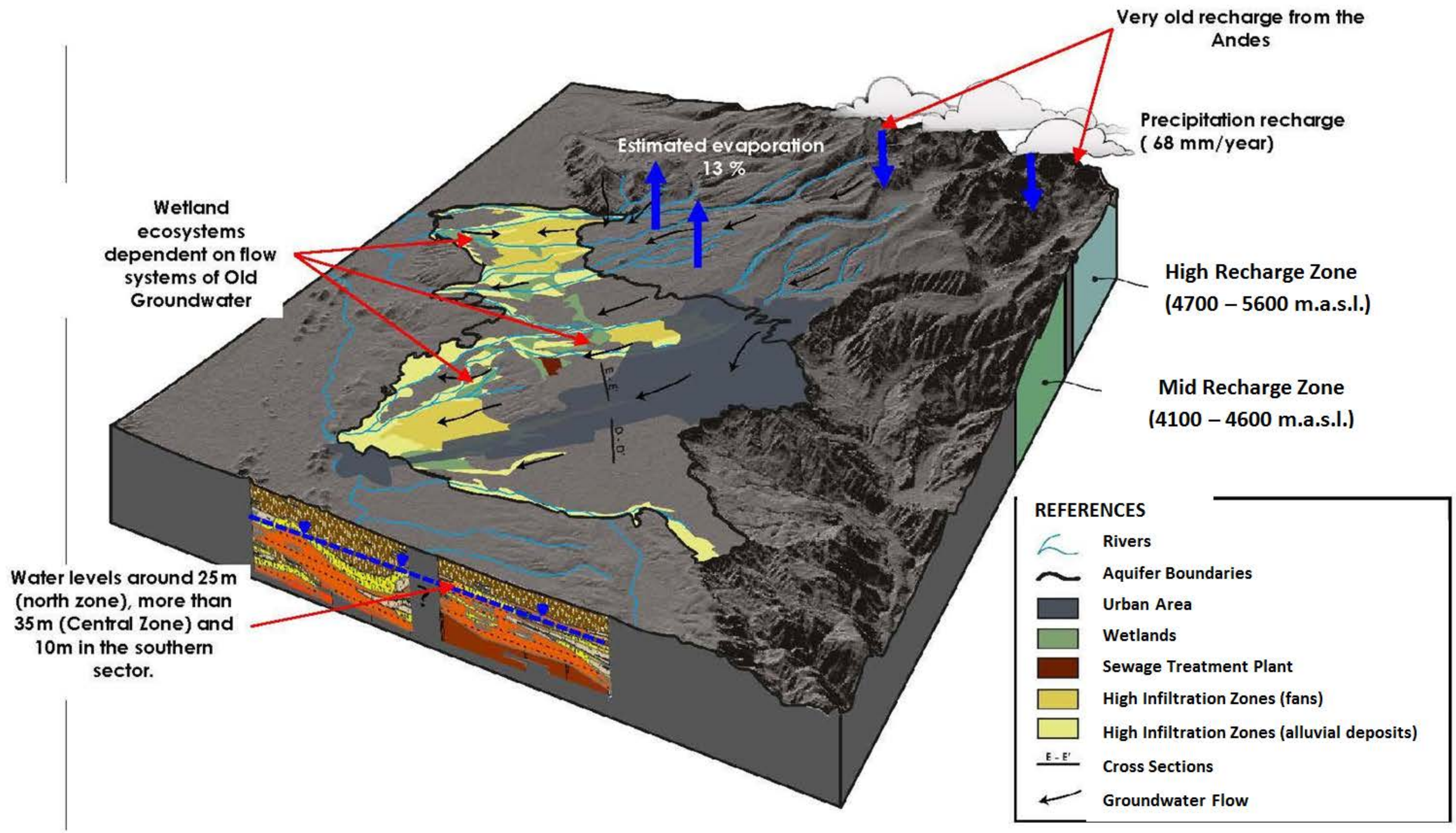

Figure 4-2 Hydrogeological conceptual model according to the results obtained applying the integrated approach of hydrogeological, hydrogeochemical and isotopic techniques. From MMAyA & VRHR, 2015, p. 64

- The northern edge of the aquifer is formed by third and fourth glaciation moraines that overlap glacial and fluvioglacial deposits. These deposits are in turn found on deposits of the La Paz formation (TLpz). In this zone, there is no significant infiltration by precipitation; therefore, this border is also a border of zero flow.
- The northwest boundary of the aquifer consists of a river, the Wilake River (belonging to the Sallani sub-basin); therefore, the boundary condition here is characterised by a flow and a hydraulic head.
- The western boundary of the aquifer is characterised by a sequence of different geological formations characterised by the Ulloma (Qul) and Cachilaya (Tcl) formations, which present clays, silts, calcareous sand and crusts, and conglomerates mixed with sedimentary rocks. Therefore, this limit also forms a non-flow boundary.
- At the southern boundary of the aquifer is the Achachicala River, presenting a very different geology; in this area the flow direction changes. Thus, as for the Wilake River, it is characterised by a flow and a hydraulic head.

It is important to note that from the boundaries of the Katari River basin, the north-western boundary of the aquifer coincides with that of the basin. However, according to the geology of the area, this limit could extend even beyond the Pucarani Municipality boundary near Battles (river Suricama that flows directly to Lake Titicaca). So it is necessary to extend and complement the studies in this area.

4.1.3 Geology and hydrology characteristics

The plain that occupies most of the study area occurs in the northern Andean Highlands and has an average elevation of 4,000 m above sea level (m.a.s.l) (MMAyA & VRHR, 2015). This plain has an almost flat topography with a slight inclination to the southwest where there are dissected hills, bogs and small foothill glacial lakes.

Many of the surface water bodies in the study area are temporary. However, perennial water courses exist, such as the Seque River that runs through the western part of the research area and flows into the Pallina River, which marks the southern boundary of the study area. This river is also influenced by the Seco River, which crosses the study area from north to south parallel to the Seque River. Other important waterways in the northern sector of the aquifer are Wilake, Poke and Chiarjahuira Rivers, as can be appreciated in Figure 4-2. Nearly all of these rivers combine with the Katari River at their downstream end, which then flows out into Lake Titicaca. It was recognised that these rivers are directly influenced by rainfall. Water flows are particularly low in the dry season. The surface water that passes the study area was 2.5 m^3/s in 1987 according to JICA (1987); this data was not updated in the other studies.

The Purapurani aquifer encompasses two sub-basins: the Sallani River (Zone 2) and the Seque and Seco River (Zone 1) as shown in Figure 4-2. These zones have guided the hydrogeological characterisation of the aquifer and helped to identify geological characteristics in the study of 2016. The area of the aquifer, from its highest to lowest depth, is formed by deposits from Catavi formation (Sct) of Tertiary sediments from the formations of Umala (Tum) and La Paz (Tlpz), and Quaternary sediments of fluvioglacial and glacier origins (VRHR, 2016), composed of layers of gravel, sand and clay (JICA, 1987). These suggest the existence of an unconfined aquifer, consisting of silty sediments of Quaternary fluvioglacial origin, characterised by the presence of clayey silt lenses.

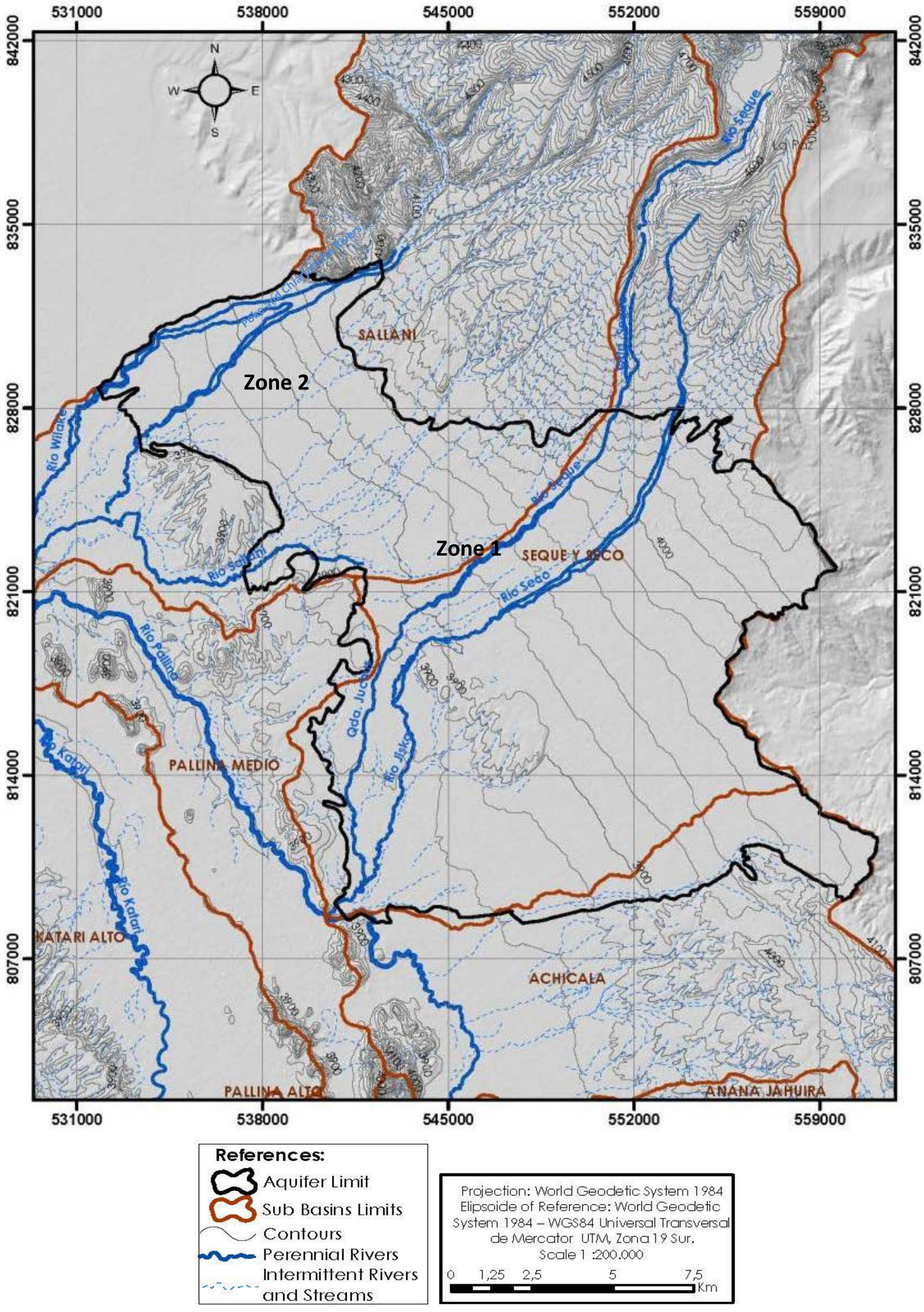

Figure 4-3 Hydrography and topography of the Purapurani Aquifer. From VRHR, 2016, p. Annex 2

4.1.4 Rainfall

The climate in the study area is typical of the highlands (4,000 m.a.s.l.) with minimum and maximum annual temperatures of -5.9 °C and 17.1 °C respectively. The annual rainfall for the period 1999–2008, according to El Alto and Viacha weather stations, corresponds to 567.3 mm (Figure 4-3). These results were based on data collected from 10 weather stations around the Katari Basin.

Potential evapotranspiration is the amount of water that could potentially evaporate from open water bodies and transpires from vegetation or other sources if there is no limit to the amount water available (AWWA, 2014). Potential evapotranspiration rates vary, depending largely on the amount of solar radiation, the latitude of the catchment area, the amount of heat, water surface area, and vegetation cover. In the study area, potential evapotranspiration is greater than rainfall in every month except January (Figure 4-4). The months with the highest and lowest potential evapotranspiration are November and February with values of 129 mm and 87 mm respectively.

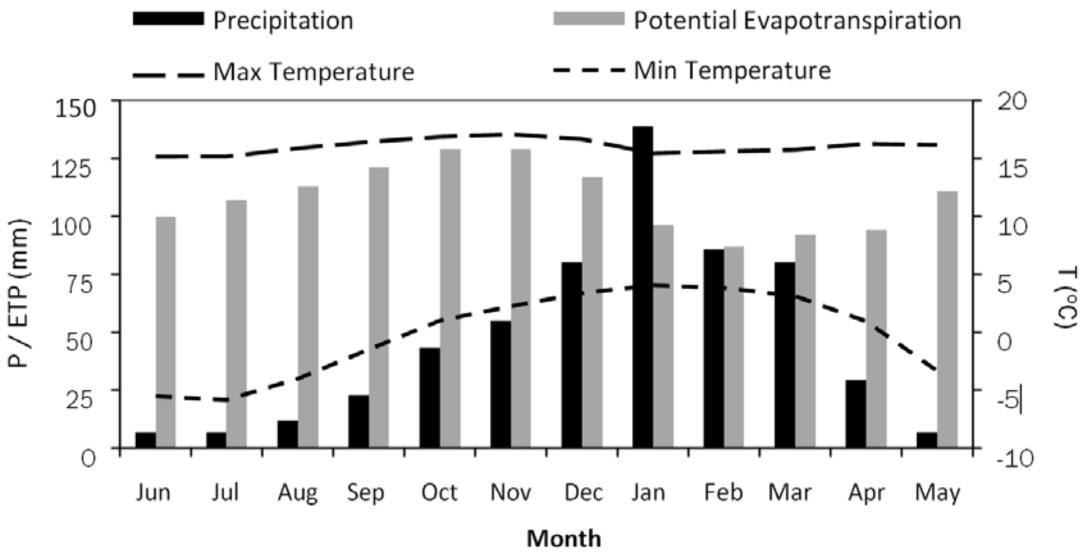

Figure 4-4 Precipitation, potential evapotranspiration, maximum and minimum temperature (1998-2008) for the stations of El Alto and Viacha. From VRHR, 2016, p. 16

4.1.5 Groundwater recharge estimation

Groundwater recharge is the primary method through which water enters an aquifer (De Vries & Simmers, 2002). Recharge is influenced by soil moisture, evapotranspiration, precipitation, and geology, among other characteristics of the area where an aquifer is located. By quantifying recharge we can recognise whether current groundwater abstraction exceeds natural recharge. If this is the case, overexploitation is occurring and large declines in the groundwater table will occur and affect groundwater-dependent streams, wetlands and ecosystems (Wada et al., 2010 cited in Jakeman et al., 2016). It is important to note that any change in the natural balance in an aquifer, i.e. through extraction, will cause a change in groundwater levels. This change will be largest in situations where the volume of groundwater extraction (over a certain time period) is large relative to the volumes of recharge (over the same time period). In this way, understanding groundwater recharge can help to better understand the sustainable limits of the aquifer.

A first estimate of recharge rates for the Purapurani aquifer, for the period of 2010 to 2014, used the chloride mass balance approach. This method is based on comparing the contribution of chloride in the rain with respect to the content of chloride that the recharge source carries to the water table. Chloride concentrations in the rain were measured at weather stations in El Alto and Viacha (Figure 4-5) from 2013 to 2014. Groundwater chloride was measured using data loggers (divers) (MMAyA & VRHR, 2015). As a result, the aquifer recharge from precipitation was estimated as having a value of 68.8 mm/year. This is equivalent to 12.3% of the average precipitation in the period 2010–2014, as shown in Table 4-2. The influence of the precipitation in the recharge was verified with the isotopic characterisation that will be discussed next.

Table 4-2 Recharge rates in the Purapurani aquifer, from mass balance of the chloride ion (CCL)

Year	Precipitation (mm)	CCLP*(mg/L)	CCLGW (mg/L)	CCLP/CCL GW	Recharge(mm)	Recharge (%)
2010	590.1	2.06	13.44	0.15	90.2	15.3
2011	538.5	2.06	16.81	0.12	65.8	12.2
2012	566.9	2.06	23.28	0.09	50.0	8.8
2013	563.8	2.06	16.60	0.12	69.8	12.4
2014	530.9	2.06	15.96	0.13	68.4	12.9
2010–2014	603.6	2.06	17.2	0.12	68.8	12.3

* The data of chloride dissolved in precipitation is an average of the years 2013 - 2014.

Note. Adapted from VRHR, 2016, p. 24

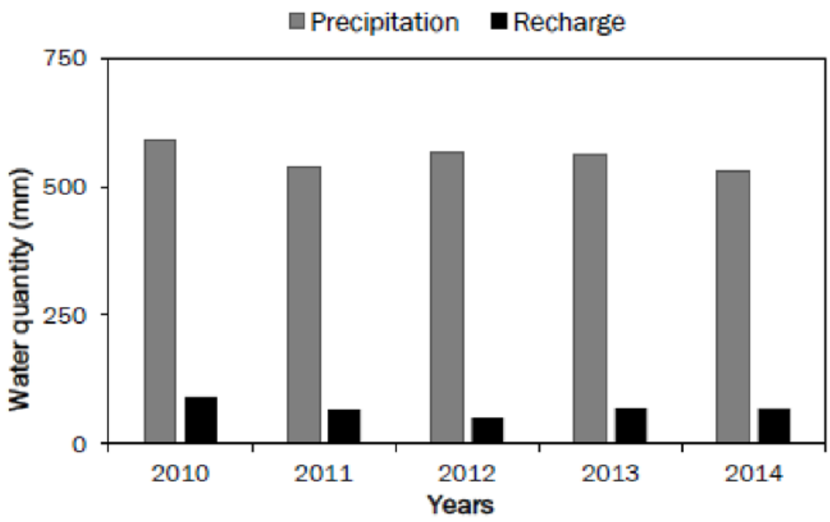

Figure 4-5 Recharge variation of precipitation in mm/year estimated by the chloride balance method. From VRHR, 2016, p. 24

According to the isotopic and hydrochemical composition of the aquifer developed by MMAyA and VRHR (2015); recharge was determined to occur during a different climate regime, probably the last glaciation experienced by the Bolivian Altiplano. The amount of stored water is attributed to infiltrations, greater than the present, in previous years. This implies that the amount of recharge at present is not related to the amount of water stored or its capacity for renewal. For this reason, the aquifer is thought to be susceptible to overexploitation. However, the amount of stored water could be increased through artificial recharge systems.

The groundwater was also found to have a strong hydraulic connection with surface water (JICA, 1987) and show a mix of recent recharge (from surface water) and old, deep and ancient water (a mixture of recharges from different events) (MMAyA & VRHR, 2015) with an evaporation loss of 13% (VRHR, 2016; M. VRHR, 2016). These conclusions are supported by the hydrogeochemical results based on the concentration of silicate. It was determined four age groups of the water in the aquifer as shown in Figure 4-6:

- Yellow area: very old recharge component.
- Blue area: old/recent recharge component (from precipitation).
- Green area: combination of old and new components (human refills: sewage and/or supply system leaks and contributions from the rivers Seco and Seque).
- Red area: recent recharge component (probably contaminated).

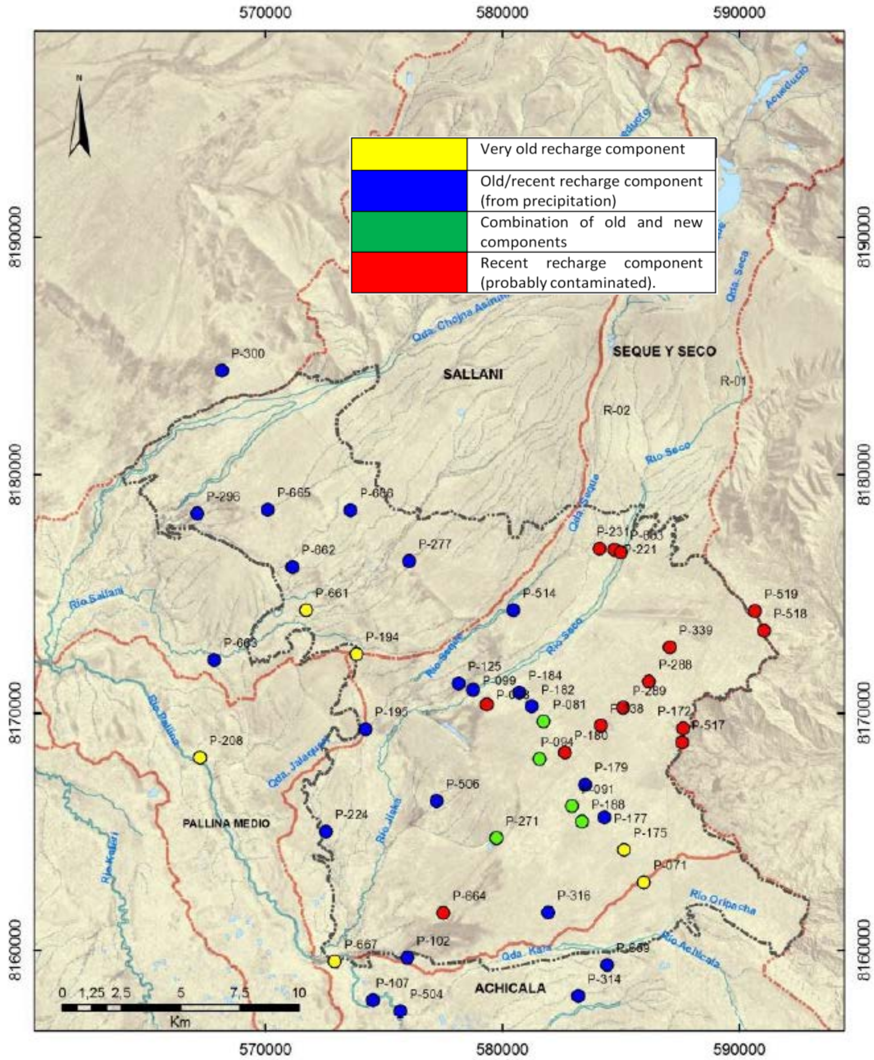

Figure 4-6 Types of recharge identified by concentration of silicate in the Purapurani Aquifer. From VRHR, 2016, p. 34

To estimate the minimum age of groundwater, the VRHR analysed the amount of tritium (^{3}H) and radiocarbon (^{14}C), remaining in the groundwater system (MMAyA & VRHR, 2015). The results showed that predominantly waters were classified as old and very old ages ranging from 800 years with recent reloads components (precipitation) with ages of 200 and 250 years; and waters being the result of a mixture between surface (Rivers Seque and Seco) and groundwater, recent and very ancient origin. Only two sampling points show water of very recent origin (MMAyA & VRHR, 2015).

Analysis using stable isotopes (oxygen $\delta^{18}O$ and deuterium $\delta^{2}H$) suggested three recharge zones (VRHR, 2016). Zone A is characterised by old recharge from a mixed source and a contribution of rainfall, Zone B shows a more recent recharge from rainfall, and Zone C has a mixed source of Zone B-type of water and surface water as summarised in Table 4-3. Groundwater recharge by infiltration of rainfall occurs from February to October, with a peak in the month of April (VRHR, 2016).

Table 4-3 Characteristics of recharge zones – Purapurani Aquifer

Zone C	• Connection with surface water • Mix of recent recharge (surface water) and old (different recharge events)
Zone B	• More recent recharge origin influenced by the contribution of wastewater • Contribution of recent local rainfall and surface water
Zone A	• Deep artesian groundwater known as "paleo waters" • Mix with the contribution of recent rainfall and probably an influence of Villaque River (north-western boundary of the aquifer)

Note. Adapted from VRHR, 2016, p. 52

The aquifer is restricted to its north edge by the urban areas of Ceja El Alto - Rio Seco - Villaque. It is important to mention that when the Aquifer is located below an urban area, there is a recharge of anthropogenic origin due to the leakage of drinking water from the distribution networks, and water served by sewer and sanitary sewage networks, and irrigation of green areas among others, which are unknown and not quantified.

The study by VRHR (2016) highlights the influence of surface water on the isotopic and hydrochemical content of groundwater, which affects the recharge of the regional and the local aquifer. This connection should be considered in the development of management strategies and the establishment of operational restrictions. On the other hand, the study identified overexploitation of groundwater of ancient origin in 2013.

To summarise, the main sources of recharge to the Purapurani aquifer can be summarised as: water infiltration of the Seque and Seco Rivers; a recharge from the melting of the snow (Huayna Potosí), whose age according to radiocarbon techniques and tritium varies between 800 and 4,000 years; recharge due to irrigation in the north-western part of the study area; and infiltration by leakage from wastewater in the north-eastern part of the aquifer (urban area) (MMAyA & VRHR, 2015).

4.1.6 Flow direction and water levels

As mentioned previously, groundwater levels are influenced by rainfall, climate, and surface water. It is important to understand aquifer interactions with surface water and recognise its influence in a groundwater system. Characteristics such as flow direction and water levels help us to identify the influence of climate seasons, location or activities such as pumping and dam construction in the water levels in the aquifer (Jakeman et al., 2016). By understanding the flow regime, the impacts of excessive groundwater extraction on groundwater-dependent ecosystems (e.g., local streams, wetlands, rivers or lakes) can be identified.

In the case of the study region, as shown in Figures 4-2 and 4-7, the groundwater flow is from north-east to south-west with changes in the south-east at the level of the highway of El Alto -Viacha. From this point there is a formation of springs that are used on the west side of La Paz, the exploitation of which is the responsibility of private cooperatives (MMAyA & VRHR, 2015).

Another significant characteristic is groundwater levels, which show the potential of external effects in the status of the groundwater system. Groundwater levels are fundamental for the identification drilling areas and regulate pumping rates, identify withdrawal limits, and establish sustainable yields. In the case when groundwater abstraction exceeds recharge over long periods and over extensive areas, the decline in water-table level affects the natural groundwater discharge, which may have harmful impacts on groundwater-dependent streams, wetlands and ecosystems (Wada et al. 2010).

In this study, monitoring wells were established in the area of El Alto, with recorded groundwater levels from 2010 to 2015. Water levels varied from 0.1 to 2.5 m in the northern area, 35 m in the central part and 10 m in the south (MMAyA & VRHR, 2015), and the piezometer levels ranged from 3,875 to 4,025 m.a.s.l.. This data is shown in Figures B-1 and B-2 in Appendix B. Water levels from east wells vary significantly from each other, as can be seen in Figure 4-8, from 2 to 100 m (VRHR, 2016). The variation in these levels can be related to the presence of industries, commerce and urban areas; for example, well P-233 is located in the Pepsi industrial area where production well depths vary from 50 to 100 m.

Based on the data collected from level meters in wells from the South-Centre and East zones, it was possible to identify two recharge events between November and March, and from March to April.

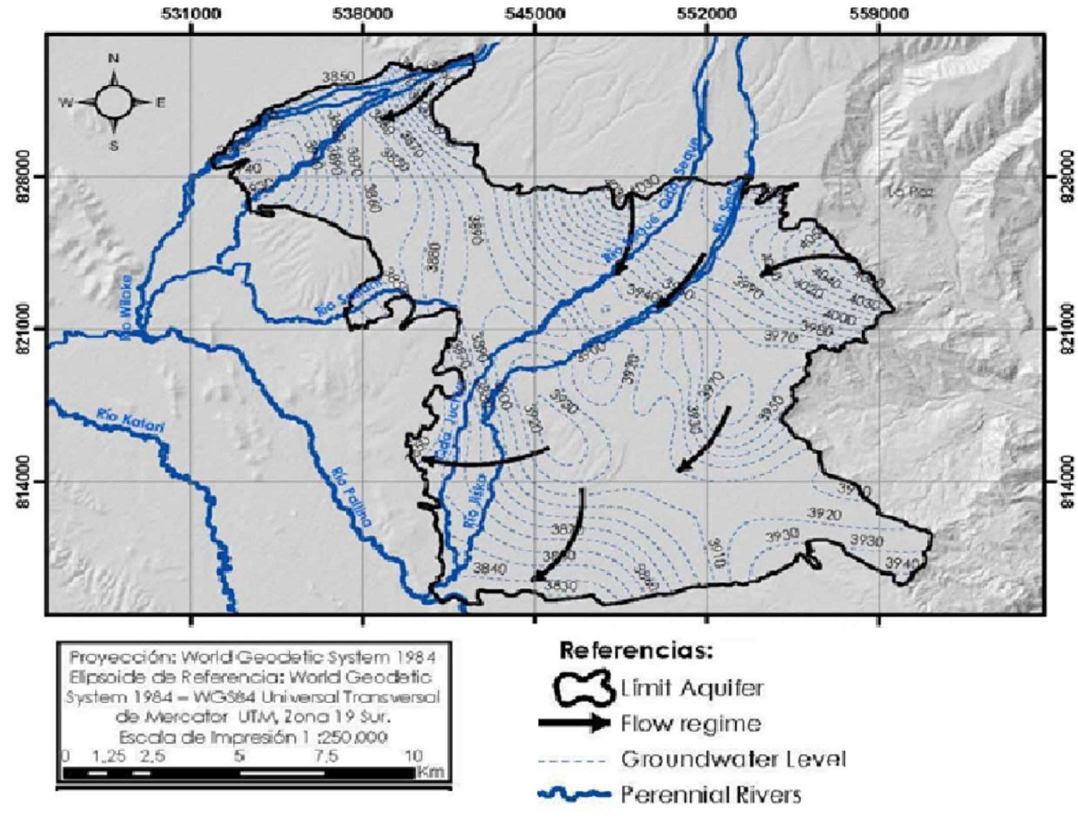

Figure 4-7 Groundwater flows – Purapurani Aquifer. From VRHR, 2016, p. Annex 2.

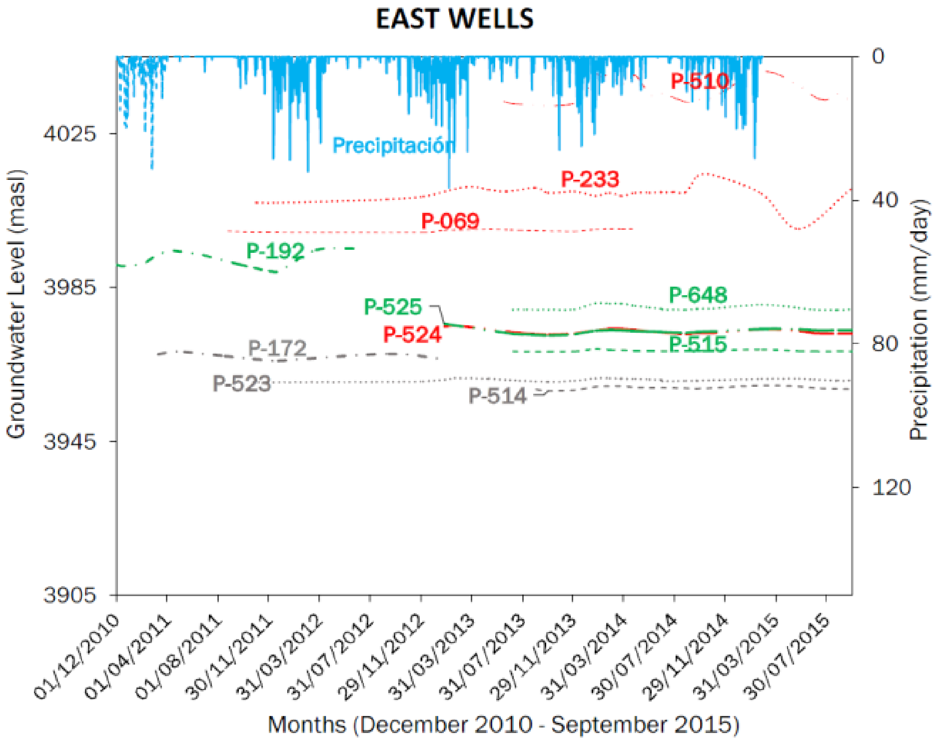

Figure 4-8 Comparison of fluctuating levels of east wells located in the Purapurani Aquifer. From VRHR, 2016, p. 22.

4.1.7 Groundwater Quality

Because of the significance of groundwater for the supply of domestic, industrial and agricultural demands, it is important to evaluate the groundwater quality. It is well known that groundwater quality is under continuous threats (Patra et al., 2016); if groundwater quality is not "good" or is below specified quality parameters, it cannot be used. Groundwater quality depends on the chemical composition as well as microbiological contamination. This is affected both by natural processes, e.g. arsenic, as well as industrial/agricultural processes.

For the analysis of water quality in 1987, water samples from 44 wells distributed along the aquifer area and its surroundings were analysed. The analysis showed that water from dams and lakes contain iron, manganese, heavy metals, some of which are poisonous substances (cadmium, cobalt, zinc, tin, arsenic, and bacteria as a result of interaction with cattle areas). Water quality in the rivers showed high levels pollution from bacteria influenced by sewage water and urban wastewater (JICA, 1987), which affected the water quality of the Purapurani aquifer. Groundwater samples showed intrusion of mine wastewater, pollution from sewage water and concentrations of heavy metals and arsenic in the northern part of El Alto, being the sources for industries such as Coca Cola and Vascal. On the middle-southern part of El Alto, groundwater quality was high and different to the shallow wells from the same area, which are polluted with coliform and bacteria (JICA, 1987).

On order to assess the water quality in the Purapurani Aquifer, the VRHR developed two sampling campaigns; 50 samples in July 2013 and 54 in May 2014.

The results are summarised in Table 4-4, which highlights components that have exceeded limits from the Regulation on Water Pollution (RMCH), the Bolivian Standard NB-512 for Drinking Water and the Drinking Water Quality Standards from the World Health Organization (WHO). The complete results are presented in Tables C-1 and C-2 of Appendix C. For their analysis, a monitoring network was established; with sampling points for collection of rainfall, groundwater (monitoring wells, production wells) and surface water (springs). The depths of the wells varied between 60 and 120 m, samples were collected from depths between 40 and 70 m (MMAyA & VRHR, 2015).

Table 4-4 Summary of results from water quality campaigns for the Purapurani Aquifer

Substance	Campaign	Unit	Range (Min. to Max.)	Within Maximum Permissible Limit	Out of Maximum Permissible Limit
pH	2013		3.8 - 7.9	47	3
	2014		6.5 -13.4	47	3
TDS	2013	mg/L	42.5 - 655.1	50	-
	2014	mg/L	NQ	-	-
Iron Fe^{2+}	2013	mg/L	NQ	-	-
	2014	mg/L	0.2 - 0.35	43	7
Manganese Mn^{2+}	2013	mg/L	NQ	-	-
	2014	mg/L	0.1 - 0.4	24	26
Chloride Cl^-	2013	mg/L	2 - 34.7	50	
	2014	mg/L	1.6 - 99.1	50	
Nitrate NO_3^-	2013	mg/L	1.1 - 60.4	38	12
	2014	mg/L	0 - 53.9	47	3
Sulphate SO_4^{2-}	2013	mg/L	8.4 - 431.1	49	1
	2014	mg/L	5.5 - 299.3	50	-
Aluminium Al^{3+}	2013	mg/L	< 0.1 - 11.5	11	39
	2014	mg/L	NQ	-	-
BOD_5	2013	mg/L	< 0.2 - 31.3	43	7
	2014	mg/L	NQ	-	-
COD	2013	mg/L	< 0.5 - 122	46	4
	2014	mg/L	NQ	-	-
Ammonium NH_4^+	2013	mg/L	0.04 - 2.6	1	49
	2014	mg/L	< 0.01 - 1.8	49	1

*NQ – Not quantified
Note. Adapted from VRHR, 2016, p. 31 -32

As a result of this water quality analysis, the study developed by the VRHR established three types of groundwater in the aquifer. The groups that have been identified are:

- Group A is characterised by the presence of ions HCO_3^-, Na^+, SiO_2 y Al^{3+}.
- Group B has concentrations of dissolved silica and high levels of sulphate and calcium ions, it is assumed that these concentrations are due to influence of external sources (MMAyA & VRHR, 2015), which change its original composition from calcium carbonate to calcium sulphate.
- In Group C there is a predominance of ions such as Al^{3+}, NO_3^-, NH_4^+, and Cl^-. Wells in this group are located in the urban area of El Alto so that water quality is influenced by urban,

industrial and mining waste effluents, and mixed with Group B waters, resulting in calcium sulphate in the water. (MMAyA & VRHR, 2015).

The results of 2013 showed that concentrations of Al^{3+} exceed all regulatory limits in a 79% of the total samples, and NO_3^-, NH_4^+, BDO_5 and COD exceed the permissible limits of NB-512, 27%, 96%, 15% and 8% respectively. In the 2014 campaign, results showed high levels of NO_3^-, $Fe^{2+}$and Mn^{2+} which exceeded limits from all three standards. On the other hand, manganese exceeds allowable limits set in the NB-512 (0.1 mg/L). The concentration of both metals can be attributed to the aquifer sediments characteristics, lack of maintenance of exploitation wells, and wastewater effluent due to the absence of sewerage system (MMAyA & VRHR, 2015).

In the analysis of NO_3^- and NH_4^+, the study identified a variation in the concentrations mostly in the urban area of El Alto which is vulnerable to discharges from urban and industrial activities. The concentrations of NO_3^- exceeded the limit of 45 mg/L established in the NB-512, by 5.2 mg/L in 2013 and 3.6 mg/L in 2014, in the monitoring well P-221. Existence of NH_4^+ in water is an indicator of possible bacterial, sewage and animal waste pollution (World Health Organization, 2004). Ammonia in drinking water is not of immediate health relevance; however, ammonia can compromise disinfection efficiency, result in nitrite formation in distribution systems, cause the failure of filters for the removal of manganese, and cause taste and odour problems. The nitrate (NO_3^-) concentration in groundwater shows an active connection and influence of leaching or runoff from agricultural land, or contamination from human or animal wastes (World Health Organization, 2004). High concentrations of nitrate lead to the condition methaemoglobinaemia; known as “blue-baby syndrome”. On the other hand, the high concentrations of ammonium are considered a consequence of the use of fertilisers in agricultural fields in the communities of Laja, Pucarani and Viacha (MMAyA & VRHR, 2015).

High concentrations of Al^{3+} were also identified; these exceeded the limits established in the NB-512 (0.1 mg/L) in both zones of the aquifer, particularly in Zone 1. The high concentration of this component is mainly due to the geological composition of the area (presence of mafic mica [ferro-magnesium] and felsic [aluminous]), and as a second source, the study considered the influence of mining activities in the area of Lake Milluni, where high concentrations were identified in surface waters that are connected with the aquifer (VRHR, 2016).

Water containing more than 0.2 mg/L of Al^{3+} should not be used for drinking water or to prepare beverages or infant formula. It is safe to use this water for other purposes such as bathing, showering, food preparation, and household chores, but it is harmful for human health, according to the WHO. Furthermore, dissolved Al^{3+} ions are toxic to plants; these affect roots and decrease phosphate intake.

4.1.8 Water balance

In order to calculate obtainable quantity of groundwater, it is necessary to develop a water balance. The first approach was developed by JICA in 1987; the balance estimated the obtainable quantity and a pumping plan. A computer simulation was carried out, taking development factors into account. The water intake was determined as 500 m^3/day (JICA, 1987).

According to the results of the computer simulations, the groundwater level would be lowered by continued water intake. This decrease in groundwater level was estimated as 25 m in 1995 and 35 m in 2000 at the well point, and it is assumed that a range of about 1.5 km from the well point was influenced in 2000. Therefore, the annual obtainable quantity should have been set up to ensure the stable intake at least up to the target year 2000.

This study proposed exploitation of the wells at 90 m depth, at a rate of 26,700 m^3/day, being a safe yield in a total of 27 wells of 1,000 m^3/day up to the year 2005 (JICA, 1987). The study recommended no groundwater development in areas near the Seco River (due to mine pollution), and in the town area (El Alto) (due to wastewater intrusion). The study also highlighted the importance of avoiding large well depths and considering intrusion from return flows in areas near farms and cattle. As a result, JICA invested approximately 26 USD million for the development of what today is known as the Tilata Water Supply System.

Water supply system development of the Purapurani Aquifer

The Tilata water supply system was based on 40 deep wells already constructed by GEOBOL (timeframe is not provided). The locations of these wells in the El Alto district were based on the results of a study developed by the United Nations. However, GEOBOL did not yet have adequate technical capabilities regarding groundwater development, and did not develop a plan for groundwater exploitation long term. For this reason, it was significant to transfer the technology on groundwater development to the Bolivian government through the study developed by JICA.

The Tilata system (dating from 1990) is supplied by 30 wells, Lines A and B, with an average depth of 90 m and an overall production capacity of 347 L/s. The system extracts water from the aquifers through two wellbore batteries – lines A and B, each with 15 wells. Wells are exploited in variable flow rates between 1.39 L/s, and 16.67 L/s. The quality of groundwater is excellent, with low turbidity, near neutral pH, low presence of typical metals in this type of source, such as manganese, and low bacteriological contamination. The area served is the border between El Alto and Viacha. The demand is 4.2 hm^3 per day and 80% is easily provided, with the remaining 20% being served by the El Alto system of surface sources (MMAyA & VRHR, 2014b).

In reference to wells of Line A, the study of 2014 concluded that there was a decrease in level, from the original values equivalent to a 105.50% lower values currently recorded (MMAyA & VRHR, 2014b). Line B showed on average a drop of equivalent to 81.84%. It is important to consider that these conclusions were made on existing information, which was categorised as insufficient.

Aquifer potential and capacity

Several geophysical investigations and well-drilling registries carried out by different state and private entities since 1987 (JICA, EPSAS), provided evidence to identify that the base of the Purapurani aquifer is irregular and that its total thickness (unsaturated zone and saturated zone) varies between 60 and 100 m. This statement is valid for the central part (sector between Airport and Tilata) where there is enough information (MMAyA & VRHR, 2014b).

The study of 2014 developed a preliminary calculation of the capacity of the Purapurani Aquifer, assuming the area of the Aquifer is approx. 300,000,000 m^2, saturated thickness of 55 m, and porosity of 15%, with specific performance of 16%. The amount of stored and potentially usable water would be 396,000,000 m^3, or its equivalent 396 hm^3, and capacity of 2.475 hm^3 (MMAyA & VRHR, 2014b). It is important to mention that this concept of usable does not consider the recharge and possible overexploitation.

The study of 2016 estimated the aquifer storage (volume of water released from storage per unit area of the aquifer and per unit of water table decline) value as 0.21 considering an average saturated thickness of 50 m (González et al., 2010 cited in MMAyA and VRHR, 2014b), with a transmissivity ranging from 872 m^2/day per metre of aquifer width. In addition, the groundwater velocity in the Purapurani Aquifer was calculated to be 2.7 x 10^{-5} m/s (estimated data considering homogeneous characteristics in the aquifer and one-dimensional flow). Considering the transport of pollutants by advection, the time it would take a pollutant to travel 100 m would be 42 days (VRHR, 2016). This data helps to establish groundwater contamination management measures.

The lack of reliable data on groundwater abstraction in the Purapurani Aquifer is a crucial impediment to the understanding of groundwater balance and its recovery. On the other hand, the isotopic results (July 2013) show that most of the groundwater exploited corresponds to very old water. There seems to eventually lead to overexploitation as this deep and ancient water is not actively recharged.

This analysis is very important because of the implications in the management of groundwater resources. Since groundwater is part of a hydrogeological cycle of recent origin, the aquifer is constantly renewed, so exploitation should be potentially sustainable. But as has been recognised, currently the aquifer is overexploited.

Hence, there is a need to plan the exploitation of non-renewable groundwater resources, and guide their use with a view to making communities better prepared socioeconomically to cope with increasing water stress as aquifer storage is depleted (Foster & Loucks, 2006a).

Water level monitoring provides essential information about the condition of aquifers and their responses to water extraction, land-use change, and climatic variability. It is important to have a spatially distributed, long-term well-monitoring network for sustainable groundwater resource management.

A pending and very important task is to improve the knowledge of the hydrogeological system of the Purapurani Aquifer through the development of investigations that aim to detail the configuration of hydrostratigraphic units in depth, the distribution of hydraulic properties such as hydraulic conductivity and specific performance through long-term hydraulic tests and observation wells throughout the Aquifer through geophysical characterisation and pumping tests.

4.2 Socio-economic framework

The following section is a result of gathering social and legal information related to the Purapurani Aquifer, its management and development. It aims to identify gaps in information and knowledge, and to develop a comprehensive framework to understand current influences of the resource in society and how it is regulated. Subsection 4.2.1 compiles information regarding social and economic characteristics of the study area: demographics, economic activities, and future trends on population growth and its influence in water demand.

Subsection 4.2.3 provides an analysis of future approaches for the management of the aquifer, and regulatory approaches with regard to groundwater management in the country. .

4.2.1 Socio-economic characteristics at regional and local scales

The Purapurani Aquifer is located in the Katari Basin (Figure 4-8), considered to be one of the most populated river basins in the country, having 11% of the population of the country (BID, 2016). The water distribution and sanitation in the area is mainly managed by public or private organisations, and/or alternative service delivery (Poupeau & Hardy, 2017). The Katari Basin extends from the Huayna Potosí glacier to the north of the city of La Paz and descends to the Altiplano to finally discharge its waters in Cohana Bay, in Lake Titicaca (BID, 2016). It is located in the state of La Paz as shown in Figure 4-1.

The most important urban sectors in the basin are the cities of El Alto and Viacha, followed by the city of Copacabana in Lake Titicaca. The basin also contains an important rural population whose dynamics are driven by its proximity to the urban centres of La Paz and El Alto (MMAyA, 2010). The city of El Alto and rural areas of Viacha, Pucarani and Laja are encompassed in the Purapurani Aquifer area, as can be seen in Figure 4-9. It is important to mention that even though the city of La Paz is not contained within the aquifer boundaries, the Tilata water supply based on the aquifer helps occasionally in the provision of water to this city. For this reason, and to explore future conditions in the water supply and demand in the region, is important to gather and analyse the socio-economic characteristics of this city as well.

Three types of population flows can be distinguished at basin level: immigration, emigration and internal flows. One of the most important population flows is the internal flow from the rural areas to the urban area of the basin. Most of the rural population moves mainly to the city of El Alto, but also to La Paz where they have greater economic opportunities, and where they can count on better services than in their communities (BID, 2016). On the other hand, there is an important temporal movement between the rural area and the urban area in which people leave their community for a certain period of time to carry out economic activities in the city and thus contribute to the family economy. The migrant population maintains strong economic and social links with the communities of origin, as well as the rights and duties corresponding to the membership of the communities. In the case of migrants to the city of El Alto, this often involves double residence (BID, 2016).

The cultural origin of the population in the basin is mainly Aymara, this being the most spoken language after Spanish. The current Aymara population has a high degree of insertion in the national society and participation in the market economy. In general, upland groups have a lower degree of vulnerability than lowland ones because of their stronger social and political organisation and their greater degree of control over their lands and territories.

Most of their socio-cultural traditions still persist, like the centred views on reciprocity with natural entities such as Pachamama or Mother Earth, mediated by yatiris (shamans), a system of reciprocity at the community level (ayni), and a political organisation focused on the rotation of authorities (thaki) (BID, 2016).

The population is organised in native communities and ayllus, these being one of the main forms of social and spatial organisation, including in the rural area of El Alto. This is characterised by being an organisation composed of a group of families linked by blood and related bonds that develop a core of economic production and distribution of consumer goods. In an ayllu, there is individual possession of the land, sayana (family property); there are also sectors of collective property, saynoca (communal arable land), in which joint rotation is practised. Also included are grazing lands shared for cattle (anacas). The Jilacata (the traditional authority) establishes rules of conduct for political, economic, social and cultural administration. A set of ayllus is a marka, which is a political, territorial, economic and social unit intermediate between the ayllu (minor unit) and the suyu (major unit), and the highest authority is a mallku (BID, 2016).

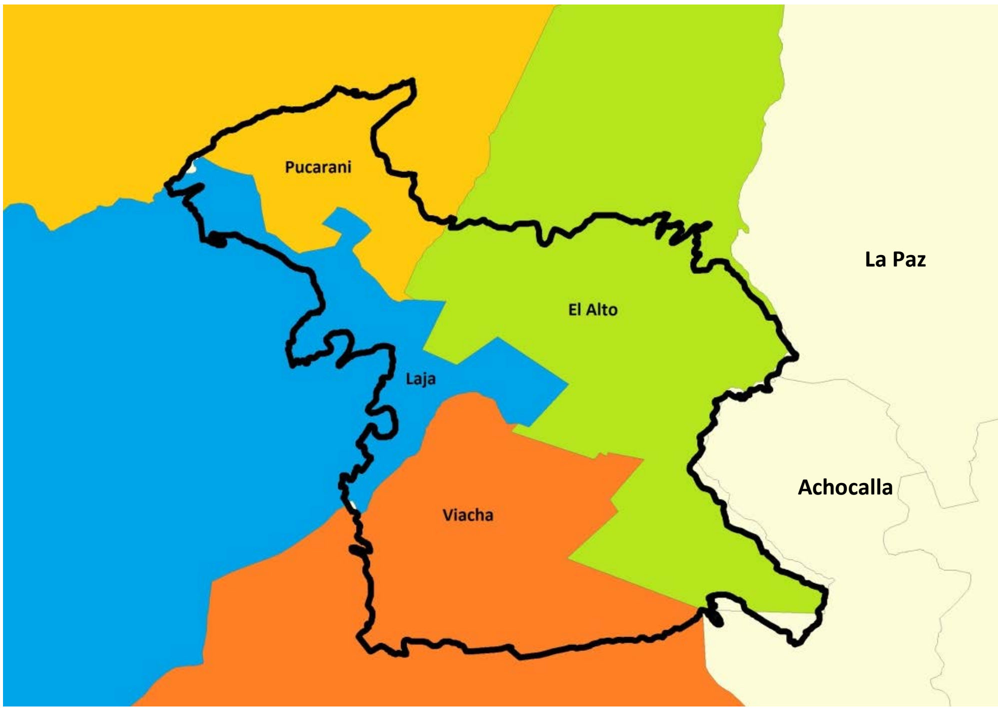

Figure 4-9 Municipalities part of the Purapurani aquifer, elaborated from Geodatabase VRHR – PDCK, 2016.

In rural areas of the Andean region, ownership in community or the ayllu is mostly collective, with usufruct rights granted to families who are members of them. In the area of influence, one of the most common organisations is the Agrarian Union of Viacha, where land tenancy is individual. About 70% of the communities within the Bolivian territory are organised under this figure, whose main functions are: to regulate relations within the community; administer justice according to the non-written codes of the Andean tradition (community justice); resolve land issues; interact with other regional authorities; appoint representatives per mandatory shift of one year (Ayni Civil Association, 2012 cited in BID, 2016).

The main economic activities in the rural sector of the basin are livestock and agriculture: potato, quinoa and barley production, as well as other crops for self-consumption. In the urban sectors, the main economic activities are retail trade and industrial production in the city of El Alto. In Viacha, the main industrial activity is the production of cement and bricks (BID, 2016). The city of La Paz organises and strengthens the regional urban system, with territorial and environmental management commensurate with productive-competitive economic development and where its inhabitants have a better quality of life. The cities of El Alto and La Paz have been connected since their origins; only in 1985 did El Alto became administratively independent, but they currently continue to share utilities (Poupeau & Hardy, 2017), as can be seen in the case of water sources and supply. Due to the growth of population in both cities, the urban area growth includes the municipality of Viacha, with the result that the metropolitan area of La Paz now is recognised as the set of the municipalities of La Paz, El Alto and Viacha (MMAyA & VRHR, 2014b).

The city of La Paz is where decisions are made regarding financial, economic and social policies of the department and the country, as seat of government of the country. The city of La Paz determines to a great extent, the urban way of life of the cities of the metropolitan area (MMAyA & VRHR, 2014b).

Political leaders have limited perceptions of the development of the metropolitan process, considering the city of La Paz as a whole and not as part of a metropolitan process that also must have basic services integrated, according to the sources of supply, consideration between systems, economies of scale and economic and financial sustainability (MMAyA & VRHR, 2014b).

El Alto is a city located to the west of Bolivia at an altitude of 4,000 m.a.s.l. in the high plateau, north-west of La Paz, and forms the largest urban agglomeration in the country (MMAyA & VRHR, 2014b). El Alto is the industrial manufacturing centre of the region, and is connected by a transportation system for both cargo and passengers, so contributing to the socio-economic sustainability, liability and equity of its population. It is the main point of entry to the city of La Paz. The range of activity is distributed in the tertiary sector of the economy with predominance in the manufacturing industry, wholesale and retail trade, and other community, social and personal services.

In addition to the El Alto International Airport, this city has a large commercial and industrial activity, with about 5,600 small and medium-sized companies (BID, 2016), factories and hydrocarbon-processing plants. El Alto bases its economy on trade and the transformation of local resources, and on commercial activity, notably the food, beverage and clothing industries, manufacturing of furniture and metal products, and activities in tannery and slaughterhouses (MMAyA & VRHR, 2014b). It is important to note that most of these activities are within the boundaries of the Aquifer, and use groundwater as a source of supply, as shown in Figure 4-10.

El Alto is considered a new city, receiving migrant population from the rest of the country, especially new arrivals from rural areas that are looking for an opportunity to improve their economic conditions. Its population has grown considerably, with El Alto obtaining the rank of province section on March 6, 1985 and subsequently the city rank on September 26, 1986 (MMAyA & VRHR, 2014b).

At present, most of the activities in the city of El Alto are concentrated in the western region, as a consequence of the high cost of living and housing in the city of La Paz. The annual growth rate, recorded in the latest INE 2012 population census, indicates that in La Paz it is −0.335%, with an urban population 761,023 inhabitants, while the city of El Alto, the population growth rate is 2.43%, with 845,445 inhabitants, showing the influence of industrial and manufacturing production opportunities (MMAyA et al., 2014b).

Viacha is the industrial centre that exports goods and services from agricultural production on a regional scale. With conditions of sustainability, habitability and equity, it has the capacity to receive and integrate the immigrant population. The livelihoods of its population are mostly industrial and agricultural, because in the city are located cement factories and the facilities of the National Brewery Factory (MMAyA et al., 2014b).

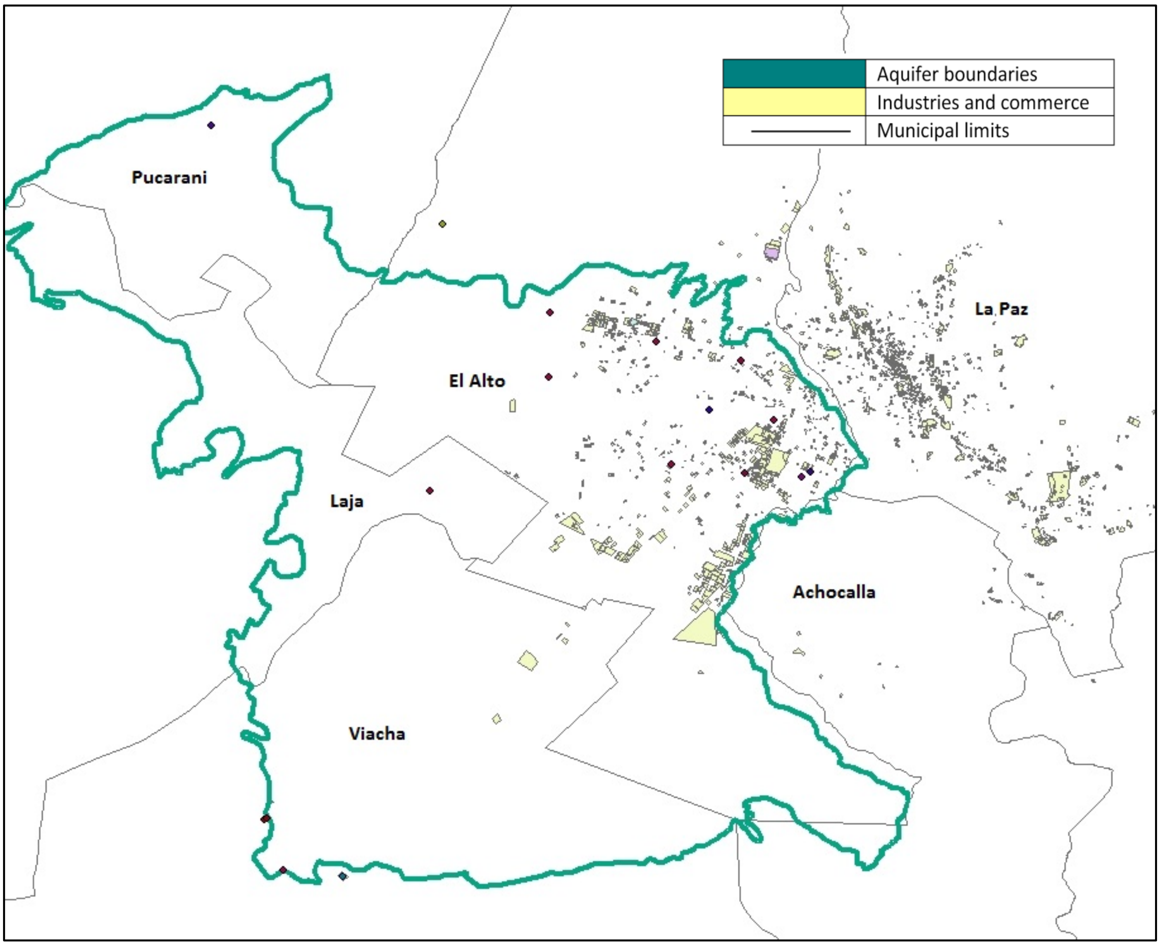

Figure 4-10 Industries and commerce in the Purapurani aquifer, elaborated from Geodatabase VRHR – PDCK, 2016.

As for the rural municipalities of Pucarani and Laja, it has been identified that the main economic incomes are from livestock and dairy production. Agricultural production has become a secondary activity, mostly to cover self-consumption. Trade in these communities is still incipient and small-scale (MMAyA et al., 2014b). There is an intense economic and social connection firstly to El Alto and then to La Paz. For example, there is the phenomenon of "Residents", people who migrated to cities to work but maintain their properties in Pucarani or Laja (MMAyA et al., 2014b).

The population in the area relevant to this study it is expected to grow by 59% by 2036, as can be seen in the total data in Table 4-4. The data and projections regarding population were developed in the Metropolitan Master Plan for Drinking Water and Sanitation of La Paz-El Alto and Adjacent Areas in 2014 by the MMAyA. This study developed an analysis of balance and demand for water resources; thus a comprehensive analysis of population growth was needed. The projection of the population in the area is based on population data according to national censuses (1992–2001 and 2012) and analysis of trends in growth rates in those periods. It is also important to mention that the study does not consider the rural population. Table 4-5 shows the growth rates for the five municipalities (urban area).

The results in Table 4-5 show that the overall urban population would practically double in the next 24 years. La Paz will grow slowly from 761,023 to 982,998 inhabitants, with a rate of 1.07%, close to the average of 0.9% registered in the period 1976–2012 (36 years). Viacha will grow 2.05 times, from 66,350 inhabitants (2012) to 136,311 inhabitants (2036), with a rate of 3.0% (2012–2036), similar to the rate adopted for El Alto (MMAyA & VRHR, 2014b). These growth rates will pressure the current availability of water resources and their supply systems.

Table 4-5 Population projection and growth for 2012-2036

Municipality	2012	2023	2036	Growth Rate
	Hab.	Hab.	Hab.	%
La Paz	761,023	855,744	982,998	1.07
El Alto	845,445	1,175,987	1,736,910	3
Viacha	66,350	92,291	136,311	3
Pucarani	2,740	3,229	3,921	1.49
Laja	1,327	1,468	1,654	0.92
Total	1,676,885	2,128,719	2,861,794	

Note. Elaborated from MMAyA & VRHR, 2014b, p. 8

Current water management

The development of the current water distribution and sanitation in the area was based on the European model of large technical systems (LTSs) (Poupeau & Hardy, 2017). This model is characterised by a continuous production of large quantities of water distributed via network pipes, operated by one public or private company (Poupeau & Hardy, 2017). This company or operator controls all the activities in the water cycle, such as abstraction, storage, treatment and distribution.

The current operator for the cities of El Alto, La Paz and District 7 of Viacha is the Public Company of Water and Sanitation SA (EPSAS). The access and supply of water for the communities of Pucarani, Laja and the rest of Viacha is controlled by the Pucarani Drinking Water Committee, Laja Drinking Water Committee and the Municipal Company of Drinking Water and Sewerage Viacha (EMAPAV) (MMAyA & VRHR, 2014b), all regulated by the Water and Sanitation Inspection and Social Control Authority (AAPS). The water supply tariff varies between sectors: the residential price is 0.33 USD/m^3 and for the industrial sector there is a range of 0.66–1.78 USD/m^3 that is based on the size of the industry (AAPS, 2014, cited in MMAyA et al., 2014b).

The drinking water service area for the cities of La Paz, El Alto and adjacent areas, considers four systems operated by EPSAS: Achachicala, Pampahasi, El Alto and Tilata. Each system has a source of supply, adductions, and treatment plant, storage and distribution networks. By 2011, these systems covered 97.55%, 84.81%, 90.95%, and 96.83%, respectively (BID, 2016).

The current urban water system of La Paz is fed by Achachicala, Pampahasi, and sometimes with contributions from El Alto and Tilata, covering 89.2% of the population demand. The source of water for these systems are small watersheds located in the mountains, which are stored in dams and then treated. This water comes from rainfall (62–79%) and glaciers (20–36%) (MMAyA & VRHR, 2014b). Even though the coverage is high, the service is restricted by insufficient hydraulic distribution networks, causing pressure and flow problems in several areas (MMAyA & VRHR, 2014b). The sewage networks are separated; one collects domestic wastewater and the parallel network collects storm water. However, cross-connections, and lack of control of discharges, among other factors, have caused water mix in the discharges. The sanitary sewer system of La Paz currently does not have a Wastewater Treatment Plant; the wastewater is discharged into the Choqueyapu River and the Orkojahuira (downstream Choqueyapu). Of the wastewater flowing into the river, 83% is domestic wastewater, and 10% is from industry. The Choqueyapu River crosses the city of La Paz so the citizens deal with foul odours and a contaminated landscape (open sewage). Moreover, downstream the water is used to irrigate 600 hectares of agricultural land, from which the products are sold in La Paz, causing several diseases (Paz Ballivián, 1997).

The city of El Alto is supplied by the El Alto water system. Regarding sanitation, 63% of households have a sanitary sewer system. El Alto is a city that has grown excessively without proper planning, which has led to informal construction systems, forcing many homes, retail businesses and industries to build their own dumping systems and connect them to the nearest water body like rain drainage ponds, or natural bodies of water such as rivers (BID, 2016). The city has a precarious drainage system, and in general, storm water and sewage discharges are combined. Some of the drainage channels terminate their discharge in the Puchukollo WWTP, while other channels collect all the drainage (including wastewater) and discharge it untreated into the downstream rivers. This has been identified as a primary source of urban contamination in the Purapurani Aquifer.

Water management and supply in the city of Viacha is divided between EPSAS and EMAPAV. District 7 is served by EPSAS with the Tilata system and EMAPAV supplies Districts 1 and 2 with water coming from groundwater from six wells covering 85% to 90% of the demand. In 2011, through the national project “Mi Agua”, two additional wells were installed to supply a fast-growing District 6 (MMAyA & VRHR, 2014b). Sanitation and drainage is partially covered by connections to the Puchukollo WWTP, but there is no evidence of amounts of sewage reaching the plant.

The municipality of Laja drinking water system has a semi-deep well, equipped with a single-phase system that is at the limit of the current needs of the population. This means that the current supply is relatively low (52.8 L/hr) (MMAyA & VRHR, 2014b). An additional problem is the risk of relying on a single source, in which different components may fail: electricity supply, pump, motor or seasons can lower the water level of the well below the pump level, as occurred in November of 2012 (MMAyA & VRHR, 2014b). The coverage reported by the operator is 91.3% in addition to the construction of new developments, so new connections are required (MMAyA & VRHR, 2014b). The WWTP is partially located in the municipality of Laja, but it treats domestic and industrial sewage collected by the sewer network of the municipality of El Alto. In spite of this, the population closest to and benefited by the treatment carried out by the plant corresponds to the localities of Puchukollo, and the south of the municipality of Laja.

The Pucarani drinking water system only has a one semi-deep well, equipped with a single-phase system insufficient for the current needs of the population. The coverage reported by the operator is 82.8%, so new connections are required. In addition, the existing storage tank has leaks and is located in a place without sufficient height to provide enough pressure to some areas of the population. In addition the energy is dissipated by friction in the distribution pipes that are of reduced diameters (MMAyA & VRHR, 2014b).

Social organisation and participation in the water decision-making process

The State promotes social participation and particularly that of service users in the decision-making processes for aspects related to the service, particularly in the elaboration of development plans, in the definition of rates, tariffs, and prices, as well as during the monitoring and control of the proper use of resources and the construction of adequate infrastructure in accordance with the rules applicable to the sector. The social organisations are the connection between the community and the decision-making institutions.

El Alto is a city with a long tradition of political participation and mobilisation. There is a strong collective organisation based on both occupational guilds (unions, cooperatives and associations) and Juntas Vecinales (Neighbourhood Boards). Among the first are the Central Obrera Regional (Central Regional Workers – COR); the Comité de Vigilancia (Vigilance Committee), and FERMIPE (Federation of Micro and Small Entrepreneurs) that includes more than 15 local productive organisations. Other relevant organisations are: the El Alto Federation of Women's Organisations (FUOPMEA), the El Alto Women's Association "Sartasipxañani", the Aymara Women's Association of Kollasuyo (OMAK), the Aymara and Quechuas Union of Bolivia (UCAB), Union of Knitters Aymaras and Quechuas (UTAQ) and the Young Producers Association "Productive Hands" of the City of El Alto (MMAyA & VRHR, 2014b). This shows the great influence of the community and indigenous people in the management process and the decision-making process within the municipality.

The Neighbourhood Boards have a legal and institutionalised functioning through Law 1551 of Popular Participation of 1994 that legalises its operation. They are constituted as Territorial Base Organisations (OTBs) with autonomous state functioning and are self-sustaining (MMAyA & VRHR, 2014b). For 2009, there were about 590 Boards in El Alto, grouped in district federations that in turn are concentrated in the Federation of Neighbourhood Boards (FEJUVE) of El Alto, created in 1979. Since its inception, this has been constituted as one of the most representative and important socio-political organisations of the region and of the country (MMAyA & VRHR, 2014b).

The municipalities of Laja, Viacha and Pucarani also show the influence of social participation in management. The community of Laja is organised in 60 small communities that are grouped into two main sectors: the original sector called Marka Kentupata, consisting of four ayllus and 20 communities, and the Central Agraria Copagira.

In the section of Viacha, the current strength of social organisation is the Central Agraria Marka Viacha, various economic organisations of peasants (OECA's), and the Santiago de Machaca and the Jesus de Machaca indigenous organisations, which defend the customs of traditional communities (Blanes, 1999). In the municipal section of Pucarani, the Central Agraria predominates, with a very strong trend towards assimilation of the values of the nearby metropolitan area of La Paz and El Alto.

Bolivian legislation establishes, in its operative regulation of Law No. 1333 of the Environment, citizen participation in the particular decision processes related to projects, works or activities, which must be carried out through the Territorial Base Organisations (OTBs). In order to comply with this regulation, there is a need to carry out public consultations to take into account comments, suggestions and recommendations from the public who may be affected by the implementation of a project, work or activity (BID, 2016). To this end, the Legal Representative of an activity, work or project must state, in a timely and adequate manner, the activity's environmental and social implications and their impacts on the habitats and population in the area affected. Furthermore, they must publish the mitigation measures envisaged, in addition to incorporating mechanisms for attending to and managing complaints, and for the coordination and information meetings with public, private and civil society institutions (Alurralde Tejada et al., 2003).

In addition, the Vice-Ministry of Drinking Water and Sanitation established a series of guidelines and recommendations for working with communities in sanitation projects (Bustamante, 2002). It specified a basis to ensure sustainability in the provision of water and sanitation services, and the implementation of participatory processes to articulate the development and community management of services with the institutional mandate of service providers (BID, 2016).

Although these guidelines do not formally establish a binding consultation process, it is important for the executing agency to promote forums that allow open community participation, where opinions, doubts or concerns about the project (s) to be developed can be freely expressed.

Future demand and development trends

The rapid increase in the rate of growth in the peri-urban areas of these cities in recent years due to the migration from rural areas, especially in El Alto, has led to unplanned settlements of the population in areas where there is no drinkable water and sewage, or where the service is discontinuous. The study developed by BID in 2016, identified that the population of El Alto and La Paz (including also the adjacent municipalities of Laja, Pucarani and Viacha) would reach 2,741,110 inhabitants by 2040, which would necessitate a water flow of approximately 4,119 L/s. Assuming these statistics, the existing water supply systems available would leave an unmet water demand of 2,519 L/s by 2040 (BID, 2016).

Faced with this problem, the MMAyA is working to develop a comprehensive, sustainable and resilient approach to climate change that will provide reliability for the water supply service for La Paz, El Alto and the surrounding cities through Basin Development Plans (PDC), the Metropolitan Master Plan and the multipurpose project of water resources for La Paz and El Alto, coordinated and financed with BID. At a national scale, the Ministry also developed the Mi Agua and Mi Riego programmes that aim to supply water for consumption and irrigation to small communities.

Three coordinated actions are highlighted: (a) actions to improve the level of service in El Alto through timely investments, improvement of the distribution network, and adjustments to the sites where the existing water sources are connected to the distribution network; (b) the short-to-medium term seeks to increase water supply; and (c) parallel to the study, a new source for drinking water, and development and improvements in sewerage and sanitation in the area.

In 2012, MMAyA identified the best alternative to increase water supply by 800 to 1,000 L/s. Alternative assessments were made, including the Jacha Jahuira (Khara Khota), Khullu Cachi (Taypichaca), Janchalani, Jacha Waquiwiña, Condoriri, Tuni, Huotos Potosí, Chojlla Jipiña and Milluni and Choqueyapu basins (BID, 2016). As a result of this study, the best alternative to increase the water supply to the metropolitan area of La Paz and El Alto and neighbouring municipalities was identified as the capture and transport of water from the Jacha Jahuira y Khullu Cachi Basins (BID, 2013).

The Metropolitan Master Plan (MMP) proposes the use of additional basins and the improvement of the current supply systems. For the Pampahasi system, it is proposed to construct a take-off in Palcoma and Chojna Khota, for the El Alto system to take advantage of the waters of the Peñas system, which includes the use of Khara Khota and Taypichaca, and for the Tilata system to extend Lines A and B of wells and include one more Line (line C). These alternatives are intended to be introduced gradually over the years 2016–2023, 2023–2029 and 2029–2036 (MMAyA & VRHR, 2014b).

The expansion of the Tilata system directly influences the current state of the Purapurani Aquifer, which will be faced with increasing production to satisfy a supply of 10.70 and 25.50 hm^3/year for 2023 and 2036 respectively (MMAyA & VRHR, 2014b). It was expected that by 2016, the San Roque water supply system, which was planned to relieve the current stress on water production in the Tilata system, would have been implemented. Based on the research online and on the field trip, it was not possible to verify if the San Roque system has been successfully implemented. The MMP proposed for a short- and mid-term of 2016–2023–2029, an improvement in the exploitation processes in Lines A and B, development of a new exploitation (Line C) of 30 wells supported by a significant contribution from the San Roque system. For the period of 2023–2036, the Tilata system is intended to supply 722.981 L/s and produce a volume of 19,963,490 hm^3 (Figure 4-11), with the inclusion of new batteries for suction in wells and the implementation of two new lines (Lines D and E) with 30 wells each (MMAyA & VRHR, 2014b).

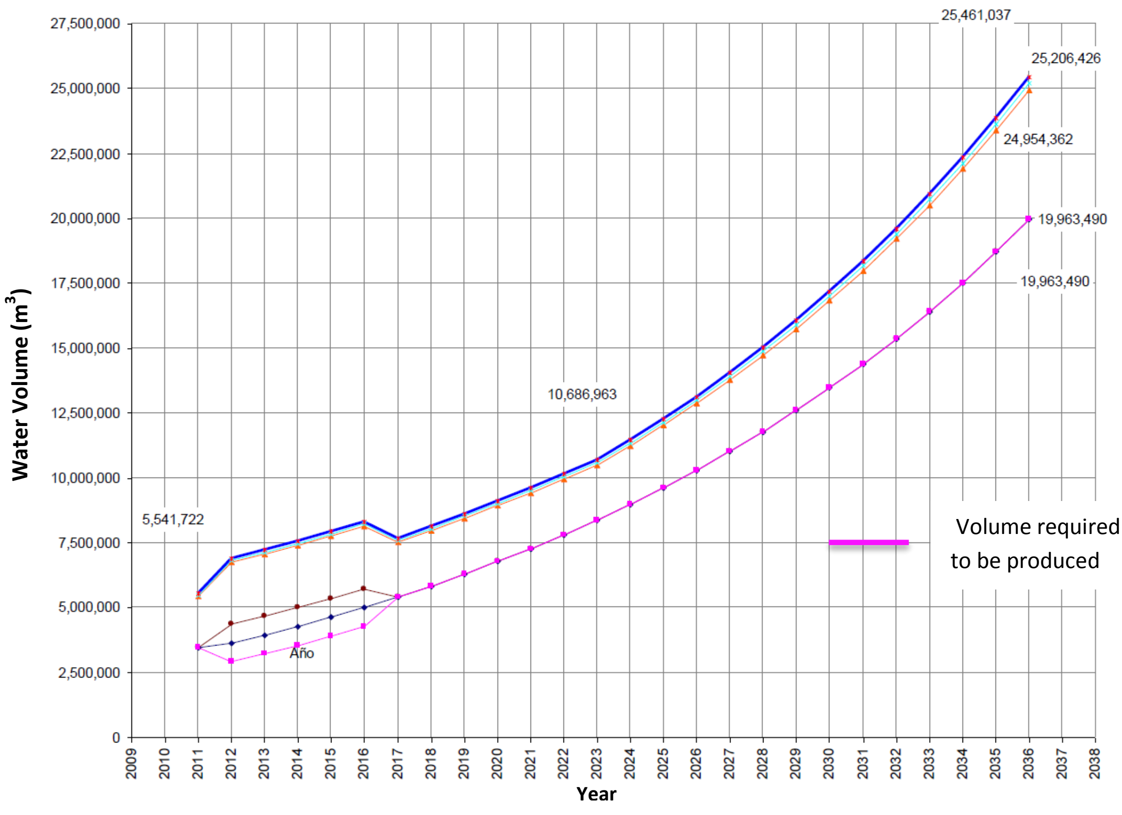

Figure 4-11 Demand increase of water volumes to supply demand in the metropolitan area of La Paz by 2036 in the Tilata system. From MMAyA et al., 2014a, p. 209.

It is important to note that the analysis developed by the MMP did not include industrial, commercial, agricultural or other economic sectors that may grow in the future in the area. Moreover, the alternative to expand the Tilata system did not consider the current contamination of the Purapurani Aquifer and water levels that are continuously reducing, recently identified in the hydrogeological characterisation of the aquifer.

4.2.2 Legislative and Regulatory Framework

Bolivia has an extensive legislation in terms of environmental regulation, and parameters for the supervision and control of the development of infrastructure projects and public services. Current environmental laws cover aspects in terms of protection, conservation, and sustainable use of natural resources. The Bolivian legal framework related to environmental regulations for the development of water resources is presented below.

It is important to develop a comprehensive legislative framework and understand the influence of the current decision-making process in the management and development of water resources in the country.

National legislative background

The administration of the country is carried out through three independent but complementary powers; the Executive branch, the Legislative branch and the Judiciary branch. The Executive branch administers finances and executes development projects and policies; the Legislative branch supervises the Executive branch, elects members of the judiciary, approves and proposes laws and settles differences between the Executive branch and the Judiciary; and finally the Judiciary administers justice at all levels. Both the executive and legislative branches are based in the city of La Paz, while the Supreme Court, the Judiciary Council and the Constitutional Court are based in the city of Sucre (Mattos & Crespo, 2000).

The government has entered a process of decentralisation by means of the Law of Popular Participation of 1994, and the Law of Administrative Decentralization of 1995. These legislations develop two processes of administrative reform and changes in the relations of the State with society. Both involve a re-territorialisation of the State and its relations with society and political life, by assigning more responsibilities to state/departmental and municipal governments (Bustamante, 2002).

The Popular Participation Law made an important step towards the delegation of powers and strengthening local governments, since 20% of the tax revenues were allocated to the Municipal Governments through a distribution mechanism based on number of habitants. The responsibility for the provision, operation and maintenance of potable water services was transferred to the Municipalities. In addition participatory planning was introduced, recognising the Territorial Base Organisations (OTBs) and social control through the Vigilance Committees was introduced (MMAyA & VRHR, 2014b). In 1995, with the Administrative Decentralization Law, part of the Executive branch was decentralized to Region Prefectures, and later, with the Supreme Decree No. 24716 of July 1997, public property and water services were regulated for a better prefectural administration.

With Supreme Decree No. 25060, of June 1998, the Basic Sanitation and Housing Units (UNASBVI) were created in the Prefectures with the responsibility of coordinating and promoting the provision of water and sanitation services and providing technical assistance to the Water and Sanitation to EPSAS. Another important step was the Municipalities Act No. 2028 of October 1999, which consolidates the powers of the Municipalities in physical infrastructure and the construction of new services and which remains the basis for the leading role of Municipal Governments in the provision of basic services (MMAyA & VRHR, 2014b).

The Law of Autonomies and Decentralization No. 31 of July 2010 took an important step in establishing the decentralization of powers to subnational governments. With this law, the regional governments have the authority not only to provide technical advice but also to concurrently finance investment projects in water and sanitation with national entities and Municipal Governments. Approval of the Autonomous Statutes of the Governments and the Organic Letters of the Municipal Governments is still pending.

Law No. 341 of February 5, 2013 on Participation and Social Control establishes that actors (organised civil society) must participate in the formulation of policies, plans, programmes, projects, and in decision-making processes, such as planning, monitoring the implementation and evaluation of public management at all levels of the State (National, subnational and local) for self-regulation of the social order because it is a right, condition and foundation of democracy. The competence to monitor and evaluate the implementation of the quality of basic services is assigned (MMAyA & VRHR, 2014b). In the water and sanitation sector, the social sector standard includes the participation of the different actors for decision making before, during and after the execution of a project, as well as in the operation and maintenance of services jointly with EPSA (MMAyA & VRHR, 2014b).

At the decentralized level, regional governments and municipalities manage the water sector in their jurisdiction. Municipalities must ensure the provision of services through a water supply and sewer service provider (EPSA) or, in the absence of that, must directly coordinate and inform the MMAyA. This structure is shown in Figure 4-12, based on the authorities that influence the management of the Purapurani Aquifer.

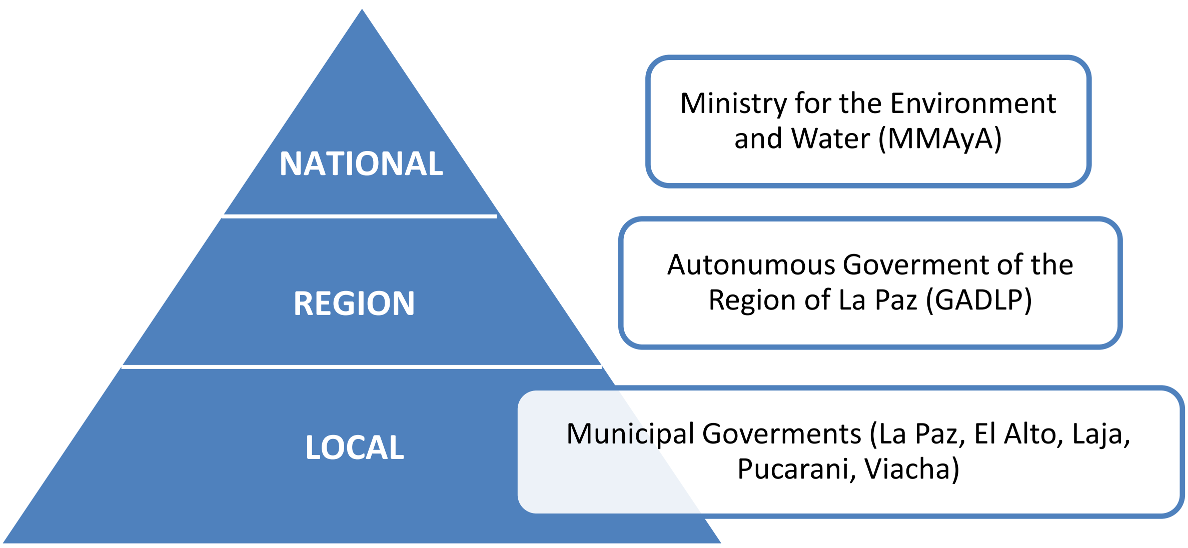

Figure 4-12 Authorities hierarchy for the management of the Purapurani Aquifer, self-elaboration

Legal Framework related to Water Resources

The current Political Constitution of the State (CPE) of January 2009 defines the state model of Bolivia as a Social Unitary State of Pluri-National Communitarian Law that is free, independent, sovereign, democratic, intercultural, and decentralized and with autonomies ("Constitution of the Plurinational State of Bolivia," 2009). It establishes in Article 16, as a fundamental right, the right of access to water, and in Article 20, recognises that every person has a right to universal and equitable access to basic services of potable water, and sewerage, among others ("Constitution of the Plurinational State of Bolivia," 2009).

Article 374 attributes to the State a leading role in water management: "it is the State's duty to manage, regulate, protect and plan the adequate and sustainable use of water resources, with social participation, guaranteeing access to water for all its inhabitants" ("Constitution of the Plurinational State of Bolivia," 2009). It also ratifies the responsibility of the State at all levels of government (State, Governments and Autonomous Municipal Governments), the provision of basic services through public, mixed, cooperative or community entities. The most outstanding is that it establishes access to water and sewerage as human rights, which are not subject to concession or privatisation and are subject to licensing and registration, according to law.

The main laws and legal provisions in force, and their characteristics in relation to the water and sanitation sector in Bolivia, are as follows:

Environmental Law

The Environmental Law No. 1333 of 1992 determines that the State promotes the planning, use and integral use of waters, for the benefit of the national community, with the purpose of ensuring their permanent availability, prioritising actions to ensure water consumption for the entire population (MMAyA & VRHR, 2014b). For the purposes of this law, sustainable development is understood as the process by which the needs of the present generation are met, without jeopardising the satisfaction of the needs of future generations. The environment and natural resources constitute the patrimony of the Nation, its protection and exploitation are governed by law (BID, 2016).

In addition, the Environmental Law prescribes that all activities, works or projects, must necessarily have the respective environmental license, according to formal technical and administrative procedures established in its regulations ("Environmental Law," 1992). This law has six regulations, modified in 1995 and 2006, that enable its implementation, of which two influence the management of water resources: General Regulation of Environmental Management (RGGA) and Regulation on Water Pollution (RMCH).

These regulations control aspects related to environmental and water management in general, specifically establishing formal procedures for the review, approval and application of Environmental Evaluations (EIA) for any activity, work or project, within the framework of the environmental impact assessment and control of environmental quality, as well as defining the powers and competencies of the governmental bodies involved in the process of environmental management (BID, 2016).

The RGGA regulate environmental management, understood as the set of activities and decisions oriented to sustainable development. In addition, it defines the institutional framework, functions, attributions, competencies and responsibilities of the different levels of public administration involved in environmental management. It regulates aspects related to the formulation and establishment of environmental policies, processes and planning instruments, administrative rules, procedures and regulations, instances of citizen participation (OTBs and others), and promotion of scientific and technological research, instruments and environmental incentives (BID, 2016).

The RGGA establishes environmental authorities at national, regional and local scales that regulate environmental management in the country. The National Competent Environmental Authority

(AACN) is responsible for formulating, defining and ensuring compliance with policies, plans and programmes on the protection and conservation of the environment and natural resources and it exercises general oversight at the national level (BID, 2016). Currently the AACN is the MMAyA. At regional level, there is a Regional Competent Environmental Authority (AACD), which establishes responsibilities for environmental management at the regional level and the implementation of national environmental policy; the current AACD for the region of La Paz is the GADLP (BID, 2016).

In Articles 9 and 12, Municipal Governments and Competent Sector Organisations (CSOs) are appointed as local authorities to implement obligations and responsibilities established by the RCPA and to regulate projects, activities, and policies in coordination with both the environmental authorities mentioned above.

The RMCH regulates the prevention of pollution and control of the quality of water resources. In addition, it defines the water pollution control system and the permissible limits of the potential pollutants, as well as the physico-chemical conditions that an effluent must meet to be discharged into one of the four types of defined receptor bodies (Mattos & Crespo, 2000). The RMCH determines how the wastewater will be disposed of, the procedures to be followed by the Municipal Governments, and the system of monitoring the quality of water resources. However, due to the transition process originated by the approval of the Law of Popular Participation, many of the provisions of the Regulation are not being fulfilled. Another reason for the delay is the regularisation of EPSA's contracts with the new regulation authority AAPS (BID, 2016).

In addition, the regulation establishes a classification of water bodies, establishes maximum permissible discharge limits and parameters in bodies of water, establishes periodic monitoring by the competent environmental authorities and determines infractions and penalties in case of exceeding the maximum permissible limits ("Regulation on Water Pollution," 1995). The bodies of water are classified according to their suitability of use

- CLASS "A" Natural water of the highest quality, which qualifies them as drinking water for human consumption without any previous treatment, or with simple bacteriological disinfection in the necessary cases verified by laboratory.
- CLASS "B" Waters for general use, requiring physical treatment and bacteriological disinfection for human consumption.
- CLASS "C" Waters of general utility, requiring complete physico-chemical treatment and bacteriological disinfection to qualify for human consumption.
- CLASS "D" Minimum quality waters, which, in extreme cases of public need, to be rated for human consumption require an initial process of pre-sedimentation, since they may have high turbidity due to high solids content in suspension, and then physico-chemical treatment and special bacteriological disinfection against eggs and intestinal parasites. (Art 4.)

The RMCH provide in its Appendix A-1 and A-2, the maximum limits of permissible quality parameters in water bodies (Art. 5). Article 6 establishes as basic parameters the following: BOD_5, COD, dissolved oxygen, total arsenic, cadmium, cyanides, hexavalent chromium, total phosphate, mercury, lead, aldrin, chlordane, dieldrin, DDT, endrin, malathion, parathion.

According to Article 7, Appendix A-1 specifies the maximum permissible values for chemical and biological parameters. On the other hand, Appendix A-2 determines the proposal (daily and monthly) of the permissible limits for liquid discharges for effluents from activities, works, projects, where there is no Class for the respective water body. The values and parameters evaluated in this regulation are described in Appendix D of this document. Article 35 establishes that the standards of Appendix A-1 can never be exceeded with discharges of wastewater once diluted in the waters of the receiving body, except for the exception referred to in Article 7.

Article 10 of the regulation gives the Governor (high authority from the GADLP) at regional level the responsibility to identify the main sources of pollution such as wastewater discharges, to propose to MMAyA the classification of water bodies, to grant discharge permits for wastewater, to approve the reuse by the same user of wastewater discharged, to develop and maintain an inventory of water resources according to the quality of water at the regional level, and to advise and coordinate with the MMAyA cases of deterioration of water quality. The Municipal Governments for their part must carry out actions to prevent and control such deterioration, and issue warnings to the Governor and to the Ministry in cases of emergency.

Articles 20 and 21 establish limits to control the untreated discharges of industrial wastewater to sanitary sewers. The permissible limits for such discharges must be established by the AAPS, so that they do not interfere with the water treatment processes in these sanitary collectors (Art. 23). Articles 24 to 28 prohibit cross-loading of sewage with storm water, and establish deadlines and procedures for correcting anomalies.

Irrigation Law

The Irrigation Law 2878, approved in 2004, regulates the use of water in the agricultural sector following a process of consultation with irrigation organisations. The law aims to manage water resources for irrigation, establish a new decentralized institutional framework and ensure the rights of use of water through a registry. Records on water sources are granted to indigenous and local families or communities, and are intended to guarantee access to water for domestic use or traditional agriculture (Bustamante, 2002).

Law of Mother Earth and Integral Development to Live Well

On October 15, 2012, MMAyA published Law No. 300 Framework for Mother Earth and integral development to live well, which establishes as one of its fundamental principles of water for life that this is considered a resource for human consumption and productive processes. The law indicates the obligations of the Plurinational State of Bolivia and the duties of society and people, through setting objectives of living well through integrated development ("Framework for Mother Earth and integral development to live well," 2012). Furthermore, it regulates aspects related to the administrative and jurisdictional protection of Mother Earth (MMAyA & VRHR, 2014b). In regard to water management, the law regulates, protects and plans the adequate, rational and sustainable use of, and access to, water components, with social participation, and the establishment of priorities for the use of drinking water for human consumption. It also aims to guarantee the conservation, protection, preservation, restoration, sustainable use and integral management of fossil, glacial, wetland, underground, mineral, medicinal and other waters, prioritising the use of water for life.

Among other goals, the law also aims to regulate and develop inter-institutional plans for the conservation and sustainable management of watersheds, aimed at guaranteeing sovereignty over food security and basic services, and the preservation of life systems, within the framework of people’s own rules and the procedures of native indigenous peasants, intercultural communities and

Afro-Bolivians, respecting their own norms and procedures, when appropriate (MMAyA & VRHR, 2014b).

Water Law of 1906

The Bolivian legislation in relation to the water resource has its base in the Water Law of 1906. It considers water is of the original domain of the State and that it is a public good. The definition of property rights in Articles 1 and 20, are based on riparian rights, e.g., waters (surface and groundwater) passing through or within the boundaries of a property, belong to the owner of the property, who may use this resource as they please without jeopardising other users.

Special emphasis is placed on the obligations or rights of the people when they are going to build waterways in lands that do not belong to them. In addition, it is considered private water if water has been used continuously for 30 years. The legislation does not establish tariffs, patents or taxes imposed for the use of water (MMAyA & VRHR, 2014b).

Chapter 4 of this law addresses groundwater specifically, recognising property owners as the main direct beneficiaries of groundwater resources located in their property. Article 21 grants to property owners the right to explore and drill wells freely in groundwater bodies in their property, although it suggests consideration for neighbouring users, but property owners are privileged with exploitation rights for irrigation purposes. This Article also establishes a condition of two metres distance between wells within communities, and 15 metres within rural areas.

In the matter of public spaces (land of the State or common areas), this chapter recognises municipalities and regional governments as authorities in charge of exploration and drilling, and also provides general guidelines and limitations for these activities. These guidelines suggest exploration activities should not put at risk waterways in their natural environment or previous users dependent on the resource. Article 25 establishes exploitation distances of 40 metres between buildings or public infrastructure like highways, and finally 100 metres distance from another spring or well.

Regarding authorisation, municipalities may grant exploitation permits to a private person when they want to explore and in the future use water from a groundwater body found in a public space. Article 29 establishes a rate of 15 to 29 USD to be paid by a private applicant for an exploration permit, and determines a period of six months to apply for an exploitation permit, requiring an explanatory document regarding use. The guidelines and provisions laid down in the articles in this chapter are not specific for groundwater bodies; they do not establish specific methods for exploration or previous studies before exploitation.

There is a specific chapter in the Water Law of 1906 in which public priority is determined over private, and that goods can be expropriated with compensation, without specifying how to price water. The ministries are in charge of water adjudication and the municipalities when waterways are under their jurisdiction (Mattos & Crespo, 2000). As this law is old, provisions referring to payments for water use, quantities and distances can be seen that under the current circumstances are not applicable. In many aspects, it can be considered a pioneering law in the establishment of property rights, but it has lost its validity, mainly due to environmental problems and the country's growth (Bustamante, 2002).

The character of this law, for the most part, is contradictory to the structural changes that Bolivia has undergone and the changes made at the international level. Alurralde Tejada et al. (2003) consider this law as a “liberal and privatizing” law because in many respects is obsolete and even contradictory to the Political Constitution of the State. The CPE establishes that water is in domain of the State (Art.136). However, the law of 1906 is in force and almost all the concessions that have involved water resources have been granted for its protection. In addition to the Water Act of 1906, there is a set of laws and decrees that regulate, modify, and/or update this law, creating a rather tangled and contradictory understanding of legal approaches.

These issues have been identified in the Water Law since 1985, leading to the elaboration and presentation of more than 30 law drafts, through which the common conclusions and suggestions were scarcity of water and the need for specific regulation. In 1988, the Senate took the initiative and presented a Water Law project, which, although it was not approved, was the main pillar for the development of new law projects (Bustamante, 2002). The last two law proposals revolve around recognising the economic value of water and its relative scarcity, recognising the benefits to society of having sufficient water and recognising the cultural value of the resource (MMAyA & VRHR, 2014b). The update of the Water Law will allow the creation of a formal system of administration based on the river basin that plans its use, according to the economic, social and environmental parameters contained in the Water Law project (Mattos & Crespo, 2000).

The Drinking Water and Sanitary Sewage Law No. 2066

The Drinking Water and Sanitary Sewage Law No. 2066 of April 2000, defines the bases of the Water and Sanitary Sewer Service Companies (EPSA) and/or management models. It determines the institutional framework of the drinkable water and sanitary sewer sector by creating institutions to monitor and regulate water resources and the financial management of income from the provision of potable water and sanitary sewerage services ("Law on the Provision and Use of Drinking Water and Sewerage Services," 2000).

This legislation determinates rates, tariffs and prices for the provision of drinkable water and sewage treatment. Also, it establishes infringements and sanctions on operators and users of the services; rights and obligations of users; and the granting of licenses and registrations to the EPSA. But it also established that the EPSA in concession areas should request the respective concession authorisation for the provision of the service, as well as the charging of fees to allow for cover operation and maintenance costs.

The purpose of this law is to establish the standards to regulate the provision and use of potable water and sanitary sewerage services and the institutional framework that governs them, the procedure for granting concessions, licenses and registries for the provision of services, rights to fix the prices, fees and rates, as well as the determination of infractions and sanctions.

Proposed Draft Water Law

In February 2012, President Evo Morales instructed the MMAyA to draft a bill to collect and enrich the contents of existing proposals. To do this, the Minister formed a committee that worked by recovering and synthesising existing proposals: the “Water for All Law” and the Draft Water Law, as well as specific suggestions from different social actors and instances of the Executive Body. This proposal set principles, definitions, duties, and rights, guarantees that express a social and environmental basis for water management, in accordance with the new Constitution of 2009.

The draft proposes a new institutional management structure, creating institutions such as the Plurinational Water Council (COPAGUA), Departmental Water Councils (CODAGUA), and the Plurinational Water Authority (APA), appointing specific functions and responsibilities to each of them. This provided a clearer structure for management. It also recognised indigenous authorities as a fundamental part of the decision-making process and management of water resources, reinforcing the autonomous regime established by the Constitution of 2009 ("Framework Law of Waters and Water Resources," 2012).

It defines water uses including those considered fundamental to life, and other uses related to extractive activities that generate a high environmental impact on the resource. By identifying these uses, it proposes a water rights regime that establishes the granting of permits, licenses and registries for the use of water, as well as for the provision of sanitation services, constraints and restrictions, as well as deadlines, revocability, sanctions and infractions in a differentiated manner, depending on whether the uses of water are for life or other uses. This regime includes a special section for cases of dumping of industrial, mining and other wastewater, and the establishment of permits based on the fulfilment of a series of requirements for the dumping and after-treatment of the waste water.

In contrast with the Water Law of 1906, the 2012 draft recognises the need for an environmental management regime. It suggests specific requirements in relation to the conservation of water sources, land use, well drilling and forestry activities related to the basin integrated management of water. It establishes the bases for the development of environmental policies in relation to water resources, and criteria and specific requirements for the environmental management of water resources.

This draft is currently in the process of socialisation, and there is no date for its approval.

Indigenous water vision and rights

In the year 2000, the Water War demonstrated the absence of water legislation that effectively expressed the rights and interests of social sectors related to human consumption and agricultural production, which, with mobilisations, defeated the recurrent intention to promote a privatisation regime (Baer, 2015). One of the triggers for the so-called Water War was the implementation of the Law of the Water and Sanitary Sewage Service No. 2029 that proposed the creation of a system of water concessions, water property markets and water markets. This law drastically affected the water rights of rural communities, and indigenous people, cooperatives and water committees, irrigation organisations and community water systems, by raising prices 300 percent (Baer, 2015). Given the implementation of this privatising water policy, which was part of the political views in force at that time, social actors of water, social organisations in the urban and rural sector mobilised to defend their rights to water, leading to the so-called Water Wars.

In January 2006, Evo Morales took office on a platform of indigenous rights, environmental protection, and a brand of economic nationalism that rejected neoliberal policies like privatisation. Morales, himself a participant in the Cochabamba Water War, expressed his commitment to putting the Human Right to Water (HRtW) into practice.

In relation to the issue of water rights, communities or ayllus in their case usually constitute a unit of allocation in irrigation systems. Internally the rules of assignment vary from place to place, often the right to water is seen as a natural right, with a riparian conception (Blanes, 1999). It is enough to be an active member of the ayllu to use water, and in the case of absent families, upon their return, they automatically reintegrate into the role of users. In addition, in most ayllus, no water rights are set for each family in terms of volumes or time, but the distribution of water depends on the community's necessity for irrigation. In this regard, there are internal regulations (agreements) to reduce water scarcity, for example by reducing the area under cultivation in a given agricultural season, when a drier than normal year is expected (Blanes, 1999).

4.2.3 Institutional Framework and Management Roles

Law 2066, Drinking Water and Sanitary Sewage, defines the institutional structure according to the following levels and main actors of the sector:

- **Normative** Level: under the MMAyA.
- **Regulatory** Level: under the responsibility of the Water and Sanitation Authority (AAPS), responsible for granting concessions, licenses, permits and registries to regulate water supply and sanitation services, seeking to promote greater efficiency of EPSAs and to protect the rights of the users and of the State (as of 2009).
- **Operator** Level: under the responsibility of the Municipal Governments, through an EPSA established by the normative authorities.

The MMAyA is formed by three Vice-Ministries: a) the Vice-Ministry of Drinking Water and Basic Sanitation; b) the Vice-Ministry of Water Resources and Irrigation, and c) the Vice-Ministry of Environment, Biodiversity and Climate Change. The Ministry is in charge of development of an integrated and sustainable management of water resources at national level, through contribution to the formulation of policies and strategies involving actors in the environmental management of water basins, respecting established uses and customs (BID, 2016).

With regard to regional levels, regional autonomous governments are responsible for providing technical assistance and implementing water and/or sanitation projects concurrently, while the municipal autonomous governments and the indigenous autonomous governments execute projects, assist in the granting of technical assistance and are entrusted or delegated to an operator EPSAS, or other organisation that has a structure recognised by the law, for example, municipal public companies, private companies, civil associations, indigenous people, rural associations, or water committees. Finally, municipal governments have exclusive control over municipal projects, or activities that include health services, basic sanitation, education, culture and sports, urban and rural cadastre systems, cultural and historical heritage, rural development and micro-irrigation. The municipal government does not grant environmental licenses, but rather receives and evaluates the environmental files and raises the reports to the departmental government.

The AAPS regulates the activities carried out by the different actors of society regarding water resources, in order to guarantee the rights of consumers, promoting the idea that all inhabitants of the country can access drinkable water and basic sanitation, and make possible the use of natural resources in a sustainable way (BID, 2016).

The EPSAS is the company responsible for water supply, treatment and provision of drinkable water and management of sewage systems in La Paz since 2006 (AAPS, 2011; MMAyA & VRHR, 2014b). It coordinates the development of plans and service expansion in the city in coordination with departmental governments. This company is regulated by the AAPS.

Currently the EPSAS is going through a period of intervention, as a consequence of discussions between EPSAS itself, the AAPS, Fejuve El Alto, and the municipal governments of El Alto and La Paz. The objective of this intervention is to decentralize the operative functions and responsibilities to streamline the process of administrative and operational tasks (MMAyA & VRHR, 2014b).

There are other institutions that have been created since 2006 that are also involved in the management of environmental resources, hence water resources. These institutions will be discussed in the following paragraphs.

The National Service for the Sustainability of Services in Basic Sanitation (SENASBA) is a decentralized public institution that was created with the purpose of guaranteeing the fundamental right of access to the service of potable water and basic sanitation. Its vision includes the design and strengthening of spaces for social participation in the management of water resources, the promotion for investment in technical assistance, institutional strengthening and community development (BID, 2016).

The Environmental and Water Enforcement Entity (EMAGUA) is a body whose objective is to implement programmes and projects within the framework of the strategic policies and objectives of development, environment and water resources, defined in the competencies assigned to the MMAyA. The entity coordinates with government actors and social organisations at the national, subnational, and international levels for the development of public investment programmes and projects in the areas of basic sanitation, water resources, irrigation, the environment and climate change (BID, 2016).

4.2.4 Current water programs and management approaches

At national level, the MMAyA has developed three major programmes for the development of water resources. These programs are: “Mi Agua” (My Water), “Mi Riego” (My Irrigation), and “Nuestro Pozo” (Our Well).

The Mi Agua programme is focused on increasing the productive capacity of small and medium-sized agricultural producers, as well as contributing to improving the living conditions and health of the population through increased access and quality in the provision of drinking water and sanitation in the national territory. It has developed several investment mechanisms, legal and technical regulations for the implementation of intensive programmes in drinking water, sanitation and irrigation, aimed at achieving an accelerated increase in coverage of services (MMAyA, n.d.-a). The programme has been implemented in three stages since 2011. The programme is currently financed by CAF (Development Bank of Latin America). The programme developed exploration activities, and exploitation development through the establishment of connections and distribution networks in surface and groundwater sources.

The objective of the Mi Riego programme is to increase the income of rural households, supported in a sustainable way through an increase in the agricultural area under irrigation and to improve the efficiency in the use and distribution of water for agricultural purposes (MMAyA, n.d.-b). The programme was implemented in 2013.

In 2016, President Morales developed the Nuestro Pozo programme with the goal to guarantee the availability of water for food safety (Ministerio de Comunicación, 2016), regulated by the Well-Executing Unit (EU-Wells) under the Ministry of Rural Development. The objectives of this programme are the drilling of wells, construction of pumping stations, installation of adduction pipes and storage tanks, installation of lightning rods and other accessories ("Programa Nacional Nuestro Pozo," 2016). The ministry responsible has the equipment necessary to drill wells where they are needed. It is necessary to point out that drilling wells do not require previous studies or exploration activities under the specifications of the programme's creation.

In 2006, after the creation of the MMAyA, national authorities recognised the need to establish a programme to promote an IWRM and Integrated Basin Management (MIC) (VRHR, 2007), creating the National Basin Plan (PNC) as a result, under the regulation of the VRHR .

The PNC is based on a decentralized implementation model, where the role of the VRHR is to guide, promote, facilitate, manage and support the implementation of actions by subnational entities, systematise experiences and disseminate lessons learned regarding the development of the different components of the PNC; their execution will be mainly carried out by local actors, municipalities, governorates, user organisations, non-governmental institutions, and other sectoral actors (BID, 2016).

As part of the hydrogeological component of the PDCK, the hydrogeological characterisation of the Purapurani Aquifer has been developed, followed by a Sustainable Management Plan. The hydrogeological characterisation has been characterised through the objectives on which the study is conducted (VRHR, 2016):

- identification of areas and amount of recharge
- identification of potential areas for exploitation of the aquifer
- identification of areas to implement strategies for artificial recharge
- determination of susceptibility to contamination of the Aquifer
- delimitation of protected areas and capture.

Currently the VRHR has developed a draft of a Sustainable Management Plan for the Aquifer (July 2016). The draft proposed a management model establishing policies and legal instruments giving the best possibility of using the underground water resource in a consensual way with the actors involved. Public participation was identified to be a critical component for the implementation and success of the management tool. The main reason for the importance of the participation of the stakeholders is that only their interest in and acceptance of the groundwater management system will enable their implementation.

Based on these principles, the Institutional Platform of the Katari Basin (Figure 4-13) will contribute to the sustainable management of the Purapurani Aquifer, taking into account the different roles and responsibilities of each of the actors involved and described in the River Basin Management Plan Katari.

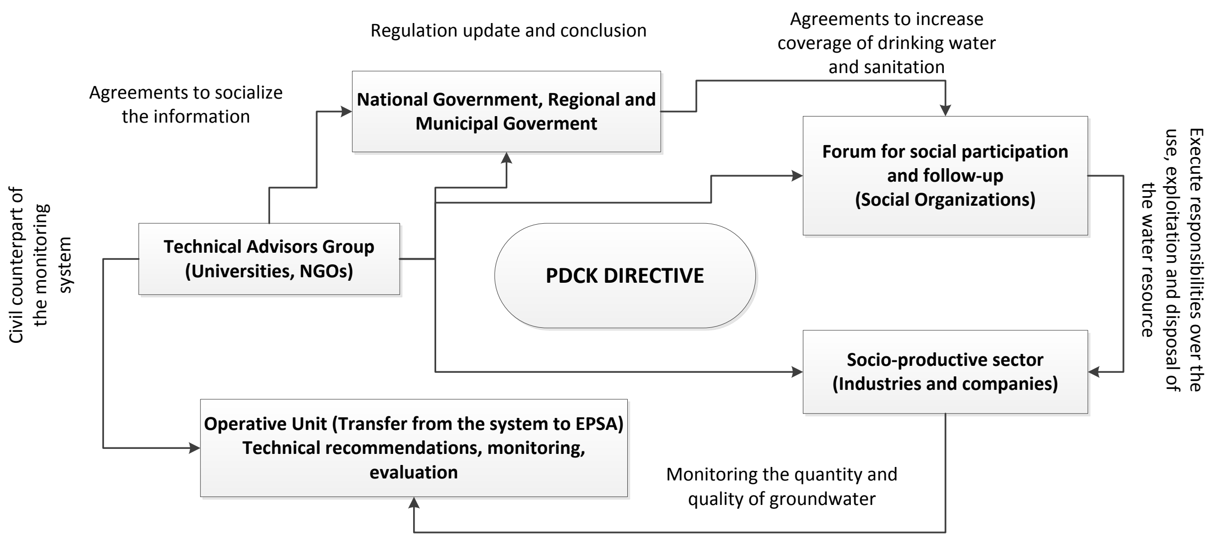

Figure 4-13 Convergence model of key actors for the Sustainable Management of the Purapurani Aquifer. Adapted from MMAyA et al., 2015, p. 69.

The Management Strategy of the Purapurani Aquifer identified in the proposal suggests Strategic Lines of Action under three main topics; Planning, Administration and Institutional Strengthening as can be seen in Figure 4-14.

As for regulation approaches, the AAPS has developed Regulatory Administrative Resolutions (RAR) for the regulation of self-supply systems for water resources (SARHs). RAR AAPS N◦ 004/2013 and RAR AAPS N. 01/2014 were proposed. As for the RAR AAPS N◦ 004/2013, it establishes a standard price of 0.42 USD/ m^3 for industrial purposes. It is important to note that this water price is subject to change depending on the industry category that would be established by the APPS. As for RAR AAPS N◦ 04/2014, it establishes the responsibility of the APPS to provide authorisation and permits for water exploitation through SARH (surface and groundwater sources) for public and private sectors, as well as to establish the conditions and costs of its operation. Each SARH is requested to complete and submit a Regularization Form for water exploitation. This form is available in Appendix E. In Section 2.3 of this form, the data requested is the drilling method, operation start date, material, depth and diameter of tubing, type of coating, static and dynamic levels, pump depth and power, and finally pumping rates in units of m^3 per month. Section 3 also requires the SARH to identify the purpose of the exploitation of the water resource.

As for future management interventions, the AAPS has proposed the implementation of a Strategic Triennial Sustainability Plan for Water Sources (PESFA) meant to be implemented by EPSAs in the country. PESFAs will provide hydrogeological information regarding water resources managed by an EPSA, and a proposal for the development of a project or study to promote their sustainability. The management tool contemplates issues such as availability, quality, ecosystem protection and risks related to the exploitation of the resource. Furthermore, a qualitative scale of assessment of the behaviour towards the protection and sustainability of the water sources has been suggested

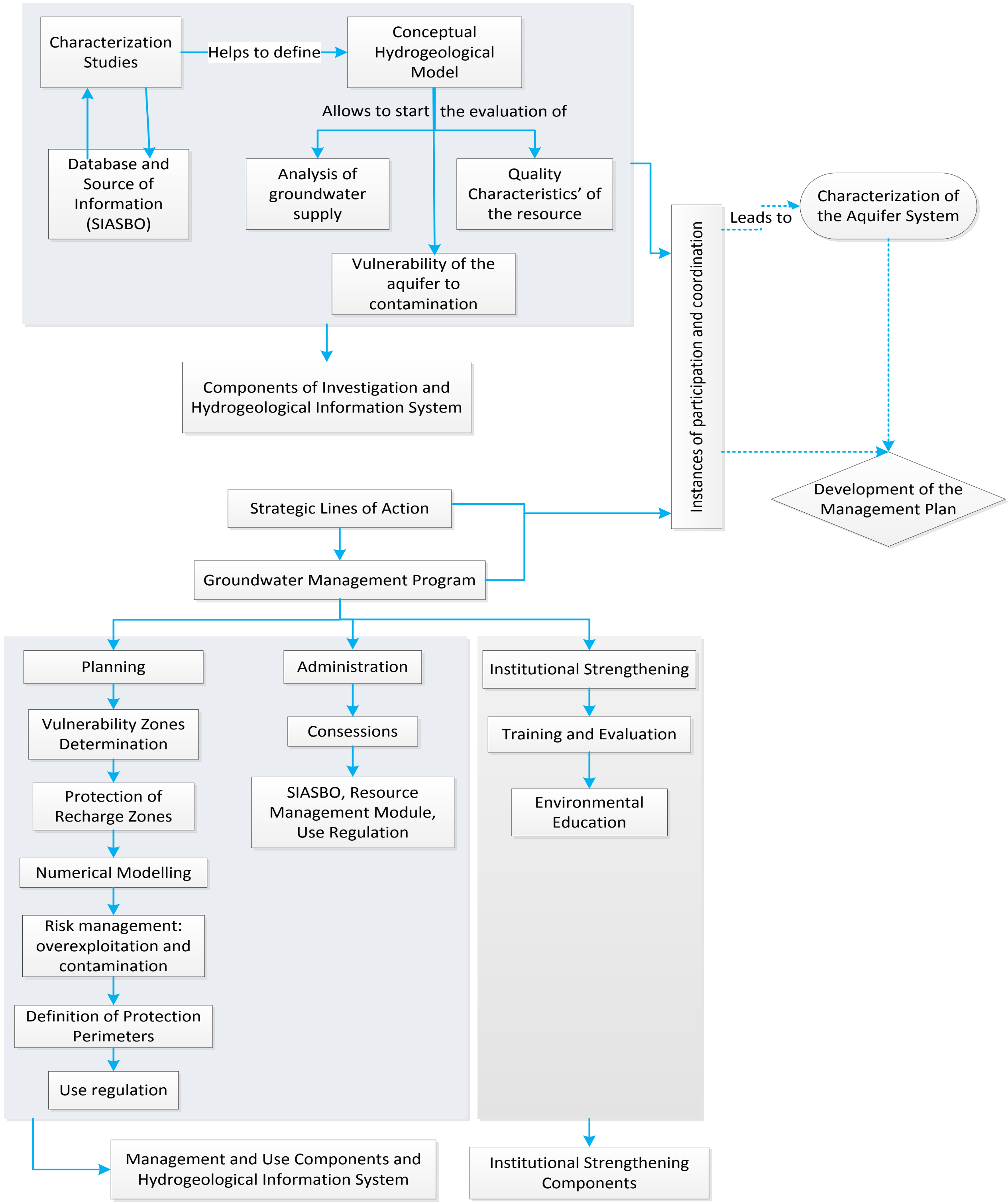

Figure 4-14 Conceptual Scheme for the development of Aquifer Management Plans. Adapted from MMAyA & VRHR, 2015, p.4.

4.3 Analysis of interviews

The goal of this analysis is to organise institutional practices with societal reality supported in the discourse analysis method, which makes visible the perspectives and starting points, on the basis of the knowledge and meanings produced in the interviews. The structure of the following section is based on Figure 3-7, and adds information regarding the participants belonging to each institution.

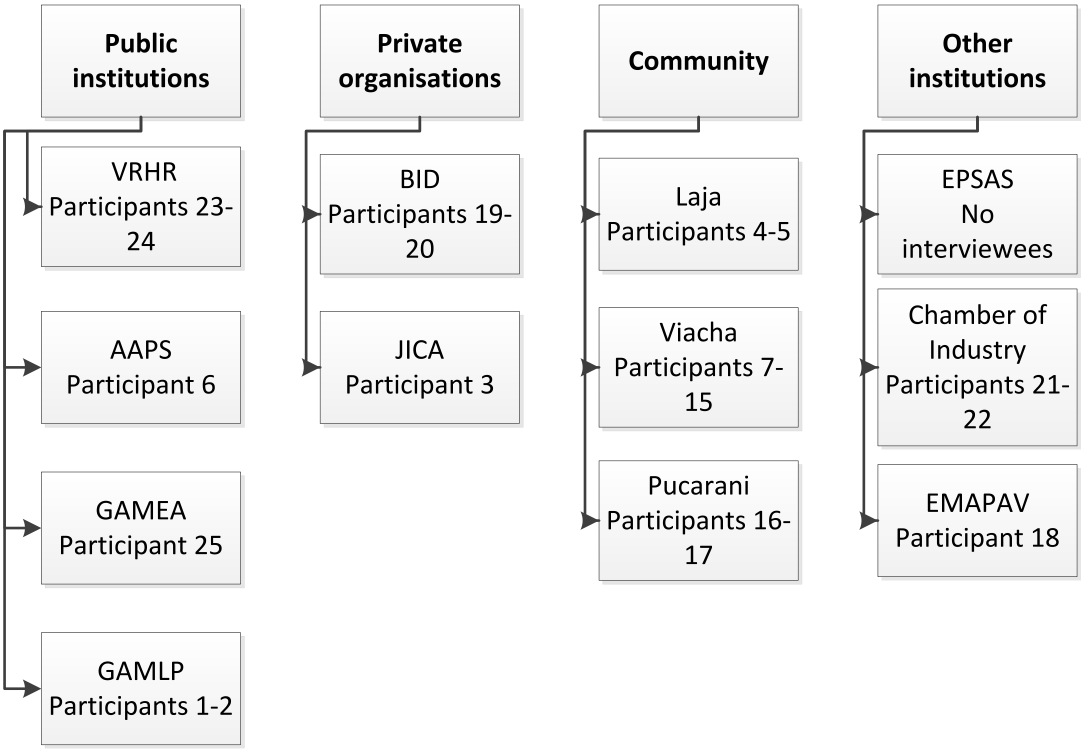

Figure 4-15 Institutions and Participants of the study

4.3.1 Public Institutions

Vice-Ministry of Water Resources and Irrigation

The main goal of the project at the beginning was to bring water to the people and provide to EPSAS basic documents so they could make informed decisions for the exploitation of future wells and improve current management.

In 2008, through finance from the Cataluña Cooperation Agency for Water, the project received funding and started. The information for the characterisation of the Aquifer was gathered but was not based in a guideline or framework, because at the time it was one of the first initiatives developed for groundwater resources in the country. Participant 24 mentions that in 2007 the sources of financial aid were interested in glacial and surface water projects and not groundwater.

The VRHR gathered all the information from scattered sources and bought monitoring devices such as meters, level meters, and so on, and started to inventory wells in the city of El Alto and surrounding communities from 2009 to 2011. The information gathered was very basic and incomplete; Participant 24 says *"this project was developed based on nothing"*. By then, the delimitation of the Aquifer was not identified yet and the wells were not georeferenced.

The main sources of information were the study developed by JICA in 1986 and various theses and projects, but these were *"scattered",* says Participant 24. The process of gathering information was strenuous, especially the field activities where the personnel of the VRHR were visiting possible places where wells could be found. Participant 24 points out that some people were very comfortable helping and opening their doors to personnel undertaking the inventory of the wells, but some were not, and most of the time lied about the current state of their wells, for example, pretending that the wells were closed and were not functioning anymore.

The project began by gathering secondary information, followed by its validation on the field, and finally developing primary information under a platform established by the VRHR. Participant 24 points out that the validation of the information on the field was the *"most difficult and problematic"*; this was mainly because of the lack of lithological information.

In December of 2011, the VRHR implemented the first monitoring network in the department of La Paz: the monitoring was done monthly, and the periods could not have been reduced between monitoring dates due "*to limited time and access to vehicle for transportation*" said Participant 24.

Based on preliminary information, for the first time, the VRHR was able to have a scenario of the system of the aquifer, its delimitation, recharge zones, water flow, and so on.

The VRHR has developed a draft for a management plan for the aquifer based on the information they have gathered. The plan was expected to be finish in 2015 but due to institutional problems the consultancy for the final design of the plan was not approved in 2015 nor in 2016, ending the development of the final version of the plan. Due to limited economic sources and time frames, the development plan was interrupted on 24 August 2016.

The monitoring programme started with five wells, now there are *"more than 15"* wells monitored as part of the monitoring network established by the VRHR: "*these are distributed in the areas of recharge, transition and discharge" says* Participant 24. The choice of these monitoring points was based on their location, but reduced by the limited economic resources to acquire monitoring tools and technology. That is why the monitoring activities are supplemented with manual measurements to ensure at least monthly measures.

The technology acquired by the VRHR will remain in the Vice-Ministry, with the goal of continuing the characterisation of aquifers in other areas of Bolivia through the Technical Unit of Dams (UTP in Spanish). This unit will be in charge of continuing the monitoring activities in the Purapurani Aquifer, as well as part of its responsibilities regarding groundwater; in the future, this unit will be responsible for the management of groundwater at national level.

The sonde have automatic measurements and the information is gathered by a dedicated computer. This computer is synchronised with a GIS database developed by the VRHR, based on information gathered in previous years.

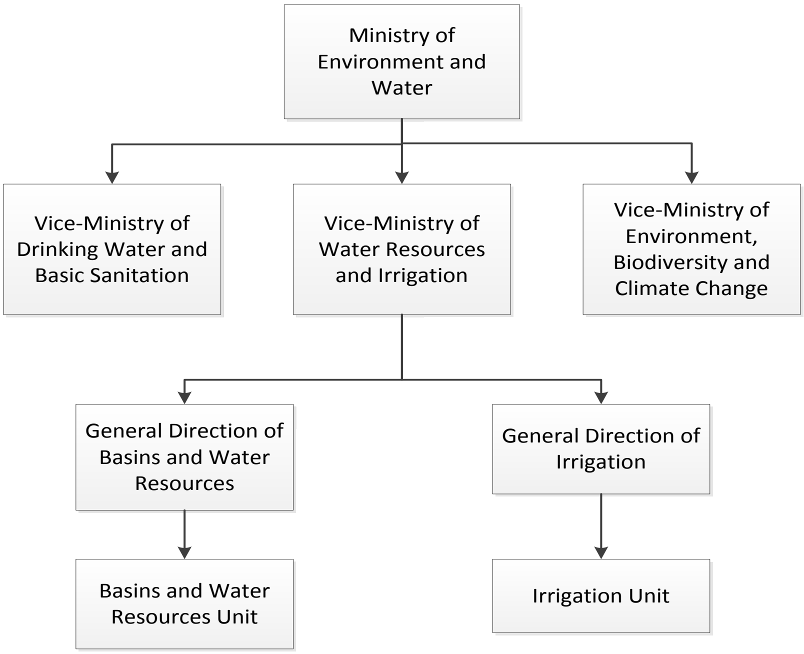

Figure 4-16 Organisation chart VRHR. Adapted from VRHR official website http://www.riegobolivia.org/organigrama.html

Two tests have been performed on the mathematical model of MODFLOW in 2013 and the second one in 2014. These tests showed a lot of "*deficiencies*" quotes Participant 24, although as a final objective it is intended that the 3D mathematical model of the aquifer will be validated. On the other hand, two other modelling tests in FEFLOW have been carried out to identify differences between software, and identify information gaps. This project was developed by the Research Institute for Development (IRD in Spanish) and, according to Participant 24, its results were not shared with the VRHR. These results could not be retrieved for analysis in this study.

In the social aspect, Participant 23 points out that over the last few year the communities have been increasing their request for wells and access to groundwater; the different rural municipalities have shown particular interest in exploiting this aquifer for irrigation purposes – they consider this a reliable source of water.

Nowadays, the Governorship of La Paz has been provided with a water well drilling machine by the Central Government of Bolivia, and as a result of the constant requests from the rural population "*the Governorship has drilled wells indiscriminately*" points out Participant 23. As a result, these wells end up being detrimental to communities, either due to intermittent water flows or excess of water leading to floods. Participant 23, as a social specialist, recognised one of the main issues as *"lack of monitoring and management training from the drilling companies".* This shows the importance of educating the communities in the management and regulation of their water resources. The case of the communities of Viacha and Laja are an example of this situation: the wells drilled in both communities are not georeferenced and there is a lack of a clear monitoring regime.

Due to the high demand from the community for access to groundwater, the President of Bolivia has instructed the Ministry of Rural Development and Land (MDRyT), to create the Water Well Drilling Company to fulfil those demands, according to Participant 23. The MDRyT has no technical experience or responsibilities, according to conversations held with the VRHR regarding the characterisation or management of aquifers, point out Participants 23 and 24. Under those circumstances, it is easy to identify several issues in this matter at national government levels: first, the unplanned creation of a company of that size without considering the consequences of promoting massive drilling; second, giving the responsibility to an entity with no experience in the matter of water resources management in comparison to the VRHR. Furthermore, in 2011, the State provided drilling machines to the military section of the Armed Forces Corporation for the National Development and Its Affiliates (COFADENA), which was responsible for the drilling of wells in remote municipalities with no access to water. COFADENA barely used these machines due to a lack of both technical capacity and previous studies to determine the drilling points, in the opinion of Participant 24, so these machines have now been given to the MDRyT for the implementation of the drilling company.

Technical capacities in the communities vary, as well as infrastructure; for example, in Viacha, the wells have been completely developed and are connected to a distribution network, unlike the situation in the town of Laja, points out Participant 24. The main reason for this difference relies on the management of the municipal governments of each community and their technical capacities; "*the Municipal Governments commit to the management of the wells as the responsible party for the drilling of the wells" and,* as a result, the management of the wells finishes in the hands of authorities with no experience or education in the matter.

One of the competences of the VRHR is to give advice, technical guidance and generate information, but it is not entitled to regulate. The VRHR generates and provides information, but the Governorship of La Paz is the institution in charge of the drilling, and the AAPS is responsible for the mechanism of regulation, which are limited to identifying and "giving a certificate" to the users, but previous technical studies are not requested before granting the certificate.

One of the examples of the VRHR in this regulation mechanism was in one of the biggest beverage industries in El Alto. By then the AAPS was also doing a well inventory, and the industry had legally reported the existence of wells in the main industrial area, but due to a study by the technicians, they discovered "*a small area that belonged to industry, two blocks down the main industrial area with five active wells, with no more than one metre of distance, pumping 5 litres per second (originally 20 litres per second) connected to the main industrial area, and they are in the recharge area*" says Participant 24. The regulatory process is limited to legally enforce the industries to declare and show their active wells, but it does not establish technical specifications of such exploitation rates, nor the distance between wells, as mentioned by Participant 24. There is information provided by Participant 18 and validated by Participant 24, that the particular company is moving in future to another area due to the reduction of water availability in the aquifer of Purapurani, clearly acknowledged by the industry too.

Participant 24 suggests the following mechanism to manage and regulate groundwater:

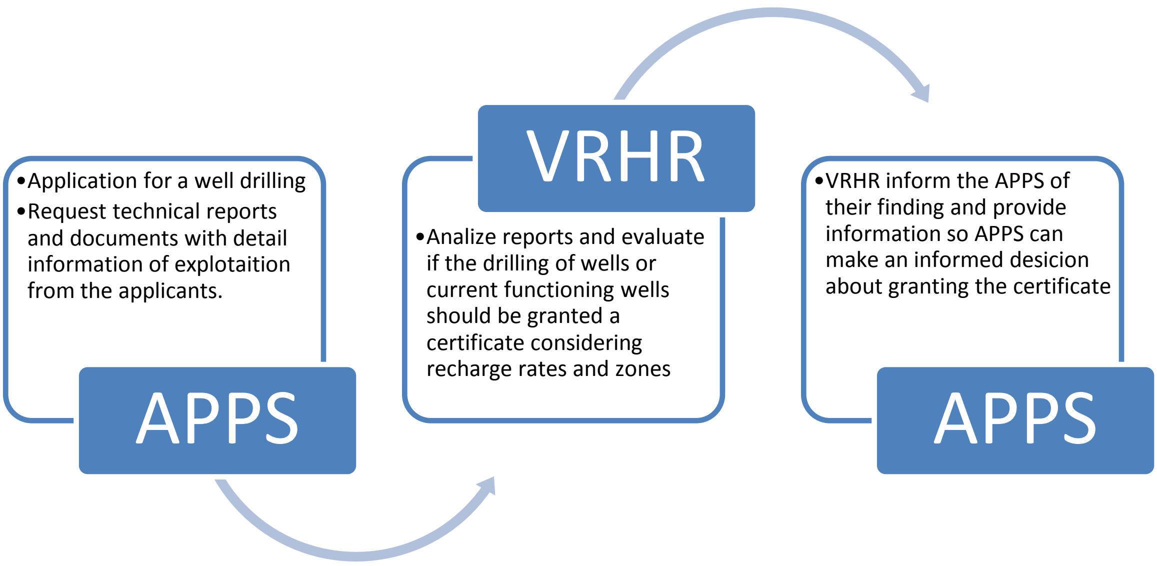

Figure 4-17 Suggested decision-making process for water management in Bolivia

This management strategy is used by the Mining Administrative Judicial Authority (AJAM) in coordination with the VRHR. Participant 23 suggests that technical reports requested in the applications should be supervised by the VRHR. On the other hand, these reports can be elaborated by an impartial institution (appointed by the AAPS or VRHR), which has no links or association with the applicants, so the information presented will be standardised and trustworthy.

Some of the programmes developed by the President were based on community demand and political ends. Participants 23 and 24 say, *"these programmes are to ensure the continuity of the current government"*. These opinions are reflected in the development of programmes such as More MiAgua, MiRiego, and the latest National Programme for Groundwater Drilling (Nuestro Pozo) approved on 2 August, 2016 ("Decreto Supremo N° 2852," 2016). These programmes share a common objective: to provide access to a reliable source of water for either consumption or irrigation for the more remote communities.

Regarding the topic of The Water Law of 1906, according to the Participants 23 and 24, the ministry has created various commissions to propose changes and updates to this law, in accordance and communication with the stakeholders involved. At the present time there is a draft of these changes made to the legislation but they have not been officially approved; as Participant 24 says *"the draft is there and we don't know if the project is going to continue*". The current legislation is contradictory: it either promotes the industrialisation or the complete protection of the natural resources.

The Publishing Unit allows the gathering and organisation of all the information developed by the VRHR; currently, this unit is being strengthened. The VRHR is also developing a communicational strategy based on an online database or library of the VRHR, mentioned by Participant 23. As a result, all of the documentation generated by the VRHR has to be in a digital format and stored in this library, the goal being to centralise the information. In regard to the Purapurani Aquifer, all the information has been stored in a Geographic Information Systems (SIG in Spanish) and is managed through a GEO DATA BASE that is constantly updated.

Findings:

- The initiative is limited by financial resources and lack of continuous communication with other institutions.
- There are similarities between the knowledge of the matter between the BID and VRHR.
- Regarding technical capacities and interpretation of data, there is no background in hydrology data.
- No previous studies have been carried out to determine the drilling points or areas.
- Management is divided, and there is no clear authority responsible for drilling.
- Human consumption needs to be prioritised before irrigation.
- The continuity of initiatives is linked to political views and relationships between Ministries.
- There needs to be further coordination between AAPS and the ministry.

Authority of Regulation and Social Control of Drinking Water and Sanitation (AAPS)

AAPS monitors, controls, supervises and regulates the activities of drinking water and sanitation, by considering Law No. 2066 of April 11, 2000 of Provision and Use of Drinking Water and Sewerage; Law 2878 of October 8, 2004 for Promotion and Irrigation Sector Support; and its regulations, while not contradicting the provisions of the CPE (AAPS, 2011).

This institution regulates the self-supply water systems in the country used for domestic, commercial, and industrial activities. There is another regulatory institution called National Irrigation Service (SENARI). Their role is to "regulate, plan and promote investment of irrigation for agricultural and forestry production" (SENARI, n.d). The current government has created these institutions with the goal of regulating water resources more efficiently.

AAPS oversees the regulating and monitoring of the self-supply system of water resources (SARH in Spanish), which are the main water supply companies in each state. They are the industries and companies that self-exploit and supply their water, as pointed out by Participant 6 from the AAPS. The SARHs provide monthly data of supply levels and water quality to the AAPS as part of its regulatory processes. The current regulatory framework is based in the dated Water Law 2066 of 1906, which is complemented by Regulatory Administrative Resolutions developed by the AAPS.

In regard to the regulation of water sources, the Authority has developed Regulatory Administrative Resolutions (RAR). Those currently enforced are the RAR 04-2013, the RAR 01-2014 and a guideline to enforce these regulations. Participant 6 pointed out that these documents are not specific, nor properly developed for different water bodies such as groundwater: *"There is no current specific regulation for groundwater resources".*

Based on these regulative tools, the AAPS provides a Certificate of Self-Supply System of Water Resources to the SARHs when they submit documentation requested by it. This documentation includes a form with details of the SARHs such as business name, location, type of business, type or water sources to be used on the self-supply system, and so on. In the case of groundwater resources, Section 2.3 and 2.4 of this form requires the following information to be filled in: drilling method, operation start date, material, depth and diameter of tubing, and type of coating. As mentioned in Section 4.2 of this Chapter.

As an approach to improve the management and regulation of water resources (surface and ground) the institution has developed a Strategic Sustainability Plan for Water Sources (PESFA in Spanish) in 2014 and five different drafts of the bill "Water for life" ("Marco Agua Para La Vida" in Spanish). These are not tools or instruments, however, that help to do an evaluation or plan for the sustainability of groundwater sources, as mentioned by Participant 6.

One of the issues raised by this participant is to how to operationalise a bill; there are background bills that provide for the management of natural resources, but there are no specific regulations developed to enforce the law, therefore it cannot be used. As stated by Participant 6: "*regulation is very important in the management of any water resource*".

Even though there is no specific regulation for groundwater resources, the AAPS currently enforces coercive methods of sanctions that are implemented to SARHs with regard to discharge processes, mainly to the industrial sector. It is evident that there are no regulations or limits provided for exploitation rates for either surface or groundwater. These sanctions are based on the monthly monitoring reports of the EPSAs of each region or municipality.

Autonomous Municipal Government of La Paz (GAMLP)

The GAMLP has developed a master plan regarding population expansion, water availability and management, called the Metropolitan Master Plan Water and Sanitation La Paz–El Alto Bolivia (PMMAPS in Spanish), as an initiative to diagnose the current water situation in both cities. Regarding groundwater, a Special Report on Sustainable Use of Sources of Surface and Groundwater was developed. This report analyses and gathers information, mainly from the supply system of Tilata, which is focused on the exploitation of groundwater in the Purapurani Aquifer in the city of El Alto. Participant 2 was part of the technical staff in the elaboration of this plan, and points out that even though the report gives a lot of information it is not *"complete"*. The report analyses the information from the current monitoring data gathered by EPSAS and the information in the study for the development of the Tilata supply system by JICA in 1987. Participant 2 identifies, as one of the biggest issues, not establishing exploitation and recharge rates in order to sustain the aquifer life, coupled with a design that did not consider population growth, nor an increase in future demand.

The current management Company (EPSAS), developed studies of the Tilata supply system to develop a new line of exploitation (Line C) in addition to the past two (Lines A and B) and these were considered in the elaboration of the PMMAPS. Furthermore, these studies lack both a complete characterisation of the aquifer and population growth analysis, and do not consider the variation of water uses in the city of El Alto: *"in El Alto there can be found industries and livestock in the same area, the use of water it is not restricted to one activity only*" mentions Participant 2.

In relation to studying water resources and availability, the GAMLP has the Risk Management Division, which is responsible for developing maps with GIS tools, although it is more focused on developing information regarding soil structure, rather than establishing water availability, according to Participant 1.

The management and exploitation of water resources has spread due to the implementation of the Autonomy and Decentralization Law N◦ 31. This law attributes each municipal government with the power to self-manage their resources and establish a management framework while providing for their own governmental institutional arrangements ("Ley marco de autonomías y descentralización," 2010). The law establishes a regime of autonomies that distribute political and administrative state functions among the municipal governments and indigenous communities, aiming to improve citizens' participation in the decision-making process ("Ley marco de autonomías y descentralización," 2010)

To develop a successful management plan for groundwater management, Participants 1 and 2 suggested these actions:

- Promote an integrated management approach within institutions and improve the communication network. The participants were not informed of the National Basin Plan developed by the VRHR nor of studies being developed on the Purapurani Aquifer. This shows a lack of communication from the Ministry to include the participation of the municipal governments (either La Paz or El Alto) in both the collection of information and the development of the management plan for the aquifer. It is crucial to integrate the municipal authorities and the community in this process.
- Set education of the population, especially for direct users, as one of the primary goals and components of the plan. Education should support the implementation of the management plan and assure its sustainability over time.
- A plan must be accessible and friendly; it must be understandable by people with all sorts of backgrounds, such as students, politicians, scientists, engineers or the community. A plan should be distributed to the communities on paper and explained in training sessions given to the communities. The language, syntax and vocabulary should be clear, direct, concrete, and simple; using technical concepts that could cause confusion or are not fully understood by the community members should be avoided.
- Explain the scientific data and principles; make the science accessible and comprehensive.
- In the case of establishing future scenarios of exploitation and management, these must be clear and based on the community experiences, characteristics and structure.
- Establish a clear procedure to collect and analyse information for the municipal governments and the community.
- Any mechanism to be proposed must be engaged with by the community and the institutions in charge of its implementation; they must feel related to the measures established in the management plan. For this reason, it is important to emphasise the co-participation of the government and the community in the development of any management tool such as the management plan proposed in this study.
- A management policy must establish a balance between necessities and demand of the community, and must consider developing a tool focused on solving issues or problems.
- The Central government should support "*these type of initiatives*" (referring to the current study), with financial aid for implementation, and encourage students to develop their studies further.

Autonomous Municipal Government of El Alto (GAMEA)

Unlike the GAMLP, the GAMEA does not have a division focused on water resources management, only a division focused on sewerage and drainage construction. Participant 25 emphasises the work of the municipal government in the construction and planning of the storm drainage and distribution network as a priority in all paving and road improvement projects.

The main projects developed by the GAMEA are mainly focused on providing a water supply for the surrounding communities and ensuring the availability of water within the city of El Alto. Most of the projects developed are based on a social demand. One of the current projects considers mainly the catchment of surface water, storage and supply for the communities of Peñas and Pucarani and part of the city of El Alto. The participant mentions that one of the reasons for the development of this project is to incorporate the concept of "water justice" in the region and promote equity in the consumption and exploitation of water, based on the availability of water in each municipality. Currently the cities of La Paz and El Alto are supplied by water resources from other municipalities; the initiative therefore promotes the exploitation of water sources available within the municipal area of the communities of Pucarani and Peñas. In the future, the concept of water justice can be further studied and implemented to compensate municipalities for the use of natural resources through the implementation of aid programmes to benefit the communities.

EPSAS is in charge of the exploitation and management of the Tilata system, which is in the area of the city of El Alto, but the GAMEA has no authority or management participation in it. Participant 25 explained that the municipal government "*just participates in EPSAS projects either through financial aid or designating areas for work or exploitation"* where these will be developed; as a result, the municipal government has limited participation in the regulation or establishment of penalty fines.

Unfortunately, there is no regulation on the drilling of wells in the country, so "*anyone is able to drill a well on their property without seeking a permit"* mentions Participant 25. On the other hand, big industries, such as Coca Cola, Pepsi and others, now need to show the quantity of wells and exploitation rates to the AAPS, which give them a permit, but there is no further regulation that establishes exploitation rates or prohibits the drilling of more wells in the future. Participant 25 points out that "*regulation is even more difficult"* because these industries are private and the access to them is forbidden without a permit or previous request, which takes time to acquire. Information regarding withdrawals is provided to the AAPS just once, before the permit is granted; however, after this process there is no official requirement for further withdrawals reports.

Currently the municipalities of La Paz and El Alto are going through a process of "metropolization of water"; this means that each municipal government wants to be in charge of the management of water resources by either dividing the current company (EPSAS) or finding a mechanism that will benefit both institutions. The goal is for each municipality to take direct control of the sources, distribution, supply and treatment of water.

The groundwater topic has not been considered in water development projects or regulation tools within the GAMEA; there is a lack of professionals and guidance in this matter. It is essential to consider the topic of groundwater in projects that involve the development of new sources of water supply, due to the connection between surface and groundwater resources.

4.3.2 Private organisations

Japanese International Cooperation (JICA)

The Japanese International Cooperation (JICA) is currently financing part of a National Basin Plan (PNC in Spanish) in the city of Cochabamba in the Basin of the Rocha River. The first step in financing the projects is to cover the demand for freshwater in the rural areas of Bolivia, not only considering distribution, but now considering climate change, which directly affects the communities through the natural phenomenon of El Niño and La Niña, "*Especially now when water supply faces a challenge due to availability of sources of freshwater"* mentions Participant 3.

Due to a lack of management at basin level, which is not operationalised, shared and practised locally, the area where the Purapurani Aquifer is located is contaminated. There is poor planning and inefficient use in some of the main sources of water.

The perceptions in Bolivia towards the management of natural resources are considered interesting and innovative due to the Law of the Rights of Mother Earth. In this law, the resources are not considered as an economic asset and are not to be commercialised. Water is perceived as a community asset and, in some places, is a productive asset.

In 1987, JICA developed an investigation to assess the groundwater balance in El Alto, and financed the development of the first groundwater system supply in the area, as described in Section 4.1 of this Chapter. The goals of the study were to collect data and undertake field surveys, review, analyse and evaluate the information, in order to identify the hydrogeological entity of the exploitable groundwater table (JICA, 1987). This cooperation was based on donations on a large scale. The main outcomes of this study have been the drilling of 18 wells in order to build a supply system known as Tilata; these wells are still being exploited to this date.

JICA developed these studies with the objective of supplying water for the growing population of La Paz and El Alto, but it did not consider future trends, nor the sustainability of the resources over the coming years. The project was a response to what was needed at that time.

Currently JICA, in collaboration with a Japanese private company, is working on a project to determine if Japanese technology (that diagnoses wells productivity) is suitable for use in the countryside of Bolivia. The main results show that 30% of the wells drilled by JICA are closed and unused; this is because of a lack of technology to maintain and mainly change filters in the wells. According to Participant 3, in the future, the agency will provide the "know how" for the technology and train the water companies in its use. This technology will remain with the wells as a legacy of the cooperation.

There is a lack of maintenance and monitoring programmes focused on water resources, no management in the recharge zone, and little regulation or protection of these areas, which are key to the sustainability of an aquifer.

The technology to implement an artificial recharge is not available in the country, even though there is a clear necessity and demand for this type of technology. Moreover, Participant 3 highlights the need to develop an "inventory" of groundwater resources available in the country, inventory them and establish a strong policy and standardised regulations to control the use and exploitation of water resources.

A very interesting point mentioned by Participant 3 is the concept of appropriation of water resources in the rural communities: *"if the river pass through my land is mine".* This assumption could be detrimental in terms of the implementation of regulation of exploitation rates.

According to Participant 3, with regard to regulation and laws that would be effective, Bolivia should firstly consider community experiences and take them to a local and then to a regional level - similar to the bottom-up management approach - and try to find common factors with international experiences, and so develop a strategy suitable for the country's characteristics.

An interesting management approach, mentioned by Participant 3, was developed by a Swiss cooperation and is based on the establishment of a small basin of 100 km^2, characterising it and establishing a management strategy for the area, facilitating its implementation and monitoring, and establishing links within and between communities. This practice is the basis of the national strategy of PNCs and could be replicated in the Purapurani Aquifer.

Any guidelines should be based on the opinion of the community (real experience), the current situation and changes in the water cycle, and should be developed within an economic, social and cultural development space. Otherwise, the community would not understand it, nor will they feel related to it, and, as a consequence, its implementation will be challenging.

Implementation would involve:

a) establishing an integrated vision of water management
b) developing a space to share this information and promote this type of initiative
c) breaking ways of thinking and concepts of management and ownership of natural resources in the community
d) developing a strategy to resolve conflicts over natural resource management through dialogue
e) implementing the TAPE approach (transparency, accountability, participation and equality), a tool considered in the Japanese decentralization process.
f) considering current needs and measuring the efficiency of consumption
g) establishing the bases of the mechanism of control: what are we controlling and what for?
h) establishing limits based on the conditions of the community, its needs and uses
i) evaluating the social cost of current uses
j) promoting education as a strong component of the plan, complementary to other objectives.

Inter-American Development Bank

The Inter-American Development Bank is currently financing the implementation of the Katari Basin Master Plan PDCK and its components including the characterisation of the Purapurani Aquifer. It has also been working on other aquifers in the country, especially in rural communities, and from their experience, the main issues they found, as stated by Participants 19 and 20, are listed below:

a) There is a lack of complete studies and information related to the groundwater resources in the country that would give knowledge to implement a development project; the few studies available are not interpreted correctly.
b) There is limited empirical knowledge of water.

c) The governorships in the country now have drilling machines given by JICA and KFW (a German cooperation) and these are under the control of their management. The machines drill wells based on community requests, without previous studies.
d) There is a lack of training and planning in the governorship and the community; there is no previous design.
e) Monitoring in the wellhead and maintenance through the following year after the drilling are absent
f) The monitoring of wells should be thorough and must include talks with the community and people responsible for change.
g) Information, gathered from all available sources, should be systematised; this process must consider field visits and must be shared with all the entities in charge, such as the governorship and the Vice-Ministry of Water Resources and Irrigation.
h) Exploitation is not controlled.
i) Contamination of aquifers is a sensitive matter because wells that are unused are not sealed.
j) There needs to be better control of industries and their exploitation of wells, and more regulation and fines in the future.
k) No planning should take place at regional level or basin level without considering the big picture
l) Municipal focus is needed to satisfy the needs of adjacent municipalities to assure the sustainability of the projects
m) The cooperation analyses the conditions of the project to fund, but the government is responsible for choosing the area. The cooperation has more expertise in their charge so they can give more feedback in the implementation of the projects and monitoring processes.
n) Work experience in the area is lacking, so international experts need to be hired. Because of a lack of technical criteria and schedules of previous studies, the lifetime of a project normally takes up to eight years due to a lack of experts in the subject and very extensive approval processes.
o) The cooperation is interested in developing hydrogeological studies to supply water to the communities and to give continuity to the projects.

4.3.3 Rural Community

The main structure for the management of water resources in the communities is through the establishment of a Committee of Drinking Water and Sanitation (CAPyS). The current management is organised by each community, which appoints their representatives. Those in charge of the water committees are called “Uma Mallku” in the native language of Aymara; they are part of the traditional indigenous organisation led by a Mallku (indigenous authority). They are in charge of the maintenance of the wells and collect the monthly charge of consumption that covers the electricity expenses for the pump and, in some cases, covers the maintenance of wells. The infrastructure for the wells and electric pumps were mainly donated and installed by international agencies of cooperation, so they became the property of the community. This structure was found to be the same in the three communities that are part of this study, as shown in Figure 4-18.

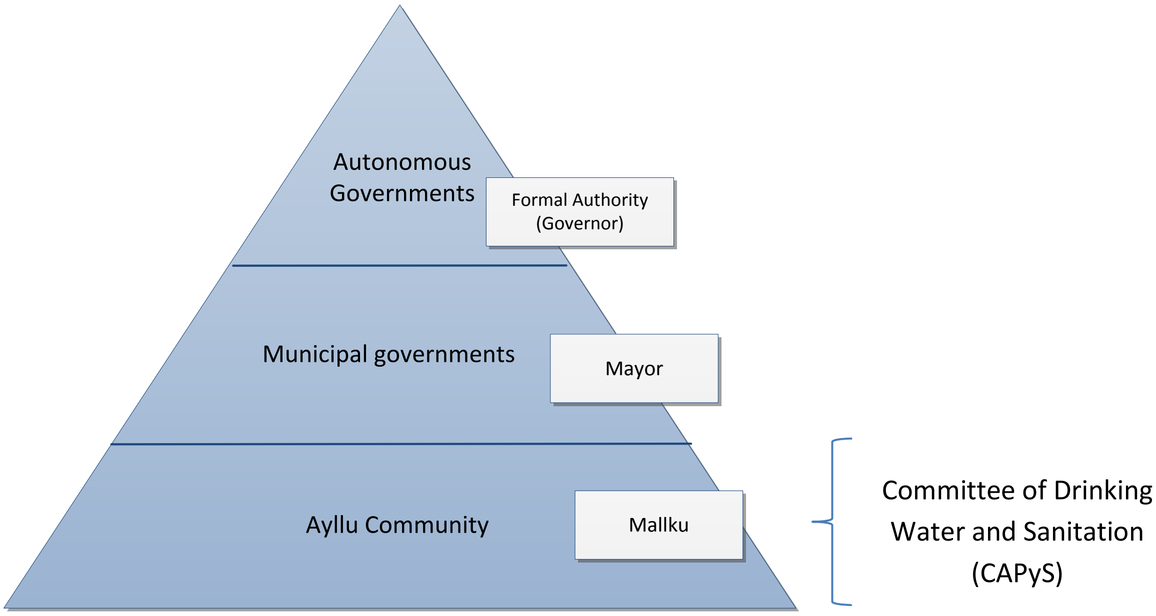

Figure 4-18 Scheme of government authorities hierarchy, adapted from Galindo Soza (2008, p. 46)

Laja

The main source of water in the town of Laja is groundwater, as it is for the 63 surrounding small communities that form part of the municipality of Laja. The community is aware of the limited availability of water resources in the region, especially groundwater; some communities are already experiencing lack of water in their wells, as mentioned by Participant 5. Now the municipality is focusing on promoting water harvesting from precipitation to solve this problem: *"Wells are dry and empty; they were drilled with no purpose"* emphasises Participant 5. On the other hand, Participant 4 gives another perspective of the current situation in other communities: some have flowing wells and the water is being wasted. This shows a lack of communication between the municipality, the members and authorities.

Furthermore, both participants have identified a deficiency in communication between the authorities from the municipality and the water committees of the communities; there is no legal or mandatory process that encourages the committees to inform the municipal authorities of their water management. It is necessary to strengthen the communication between authorities to facilitate the collection of information to develop a basic diagnosis of the current situation. as acknowledged by Participant 5 who notes: "*we need to survey the active wells and understand how they are being managed; we don't know how their wells are functioning".*

The main communication medium is radio or through official statements – these characteristics are fundamental in the development of a management plan; they should be considered in the suggestions under education and technology. The limited access to technology for this community is a key factor in developing activities and regulatory measures; in order to ensure water sustainability these limiting factors should be considered.

In the community of Laja, the price paid per quantity of water consumed is fixed; the price is not related to the amount of water that each person consumes. The amount of water available in the wells is just enough for domestic use; there is not enough to be used for irrigation or given to their livestock, and the groundwater is already very limited, pointed out Participant 4. This is supported by Participant 5 and adds the variability of the water quality in the wells to the current issues: "*in some communities the water is not even appropriate for irrigation",* it is high in turbidity and sometimes even contaminated*.* Now the municipality is trying to find finance for irrigation.

To implement a management plan, Participant 5 suggested that the whole community should be involved in the elaboration of any management tool, facilitated with the final approval and endorsement of the community, because they feel included in the development of the document. As Participant 5 says: *"it must be done through a consensus with the community".*

It might be helpful to centralise all the information in the municipal governments so they would be responsible for the management and regulation of their water resources; this suggestion is supported by both Participants 4 and 5.

Based on both participants, the main findings are:

- Installation of personal meters is needed.
- Water committees in the communities should be strengthened by providing technical training and education.
- A water company specified by the municipal government of Laja should be established.
- Information for each community should be developed and measures established based on their individual characteristics.
- The community should be informed and taught through assemblies, meetings and focus groups in a more direct and personal way, with the help of visual aids and presentations to share information.
- A municipal regulation needs to be developed to facilitate the implementation of limits and monitoring programmes.
- No monitoring programmes are in place and no plans exist for development in the future.
- The technical capacities within the municipal government are limited by education and experience in the topic.
- A need exists for education and training in management tools and current legislation regarding natural resources with a focus on water. The participants showed some knowledge of national and regional regulations, although not in depth.
- The participants showed difficulty in understanding technical language, concepts and vocabulary, such as "groundwater", "recharge rates", and so on.
- There is a lack of communication within the municipality: based on separate interviews, both participants provided information sometimes different from each other on the same topic.
- Limited access to technology is available – the main sources of communication within the town are via radio or cell phones. Access to the internet is expensive, so it is not accessible for the community.

Viacha

The main source of water for the community is groundwater; wells have been installed by the international cooperation agencies (NGOs) and their management is divided between the EPSA (EMAPAV in Spanish), and self-management by the 60 surrounding small communities that are part of the municipality. In order to open a new well, EMAPAV has to request permission of the municipal government and the indigenous organisation of “Jacha Marka Originaria Viacha”, due to jurisdiction. Even so, the indigenous authorities point out that EMAPAV manages water in an “*arbitrary way”,* raising the monthly prices, based on rates that have not been established consensually. Because of this, most of the issues regarding water management are resolved through the highest authority of the community “Mallku”, who oversees all the decisions taken in the communities that are part of Viacha.

The main uses of water in the area, besides household consumption, is cattle raising and dairy farming; currently there are no horticultural activities due to the limited quantity of water available. Unlike in the communities of Laja and Pucarani, the water available is influenced by the presence of one of the biggest cement industries, “SOBOCE”. In the last few years, the availability of water has been reduced as mentioned by Participant 7: *“before, water pressure was strong, now it has been reduced”*. Up to date there is no technical information on the exploitation of groundwater, point out Participant 8, 9 and 10.

The indigenous authorities of Viacha are concerned about the reduction in the availability of water over time; they are now feeling the impacts of climate change. Participants of Viacha have mentioned that the availability of water resources has decreased significantly and have expressed their concern. Participants 11, 12 and 13, from remote communities, experience limited availability of water as noted by Participant 13: *“we have no water now”*, and are very concerned about the future of their communities. Some are not able to cover their basic needs (for drinking water), and others have to sell their livestock (because there is no water for irrigation of grasslands nor for consumption by animals) and must change their economic activities to have some financial profit. Most of the participants have shown a particular interest in projects to develop irrigation in their communities.

Participants 10 and 15 mention that their communities had wells drilled but there is no infrastructure to make the connections to the households; this implies long walks and the carrying of heavy containers from the wells to their homes. This situation shows a lack of monitoring after the drilling activities; it is necessary to emphasise the need to promote monitoring programmes as the responsibility of either EMAPAV or the municipal government.

In these communities, the procedure for requesting access to potable water from the competent authorities, in this case the municipal government is lengthy, as mentioned by Participants 11, 12, 13, 14 and 15. Some of their communities received their responses in a timeframe of 6 to 48 months. *“Sometimes when they answer, the municipal government sends someone that does not know about the topic, it does the drilling without previous knowledge, now that well has no water”* mentions Participant 13. The community representatives are constantly looking for guidance and institutions that can help them; they do not know who they can approach.

Participants mention that the best approach to share information is to explain things directly through training sessions and community-based documents.

The main findings are:

- The community’s representative is not aware of the management between the municipal government and the industry.

- Any document should be familiar with the characteristics of each community.
- The information should be accessible and friendly, not include technical terms but be educational and in Spanish.
- The highest authorities are not aware of the projects taking place in their area, the water availability, the legal framework and their rights over their natural resources management.
- Communities do not know which authority to resort to solve their problems regarding water availability.
- The communities are interested in developing irrigation systems to sustain their livestock activities.
- Drilling wells should not be done without previous characterisation studies.
- No monitoring programmes are currently put in place.

Pucarani

There is a mixture of water sources in this municipality: surface and ground water. Regarding groundwater, the community is facing problems of availability and quality (because of contamination); *"communities are consuming contaminated and highly salty water due to there being no other source of water*" as mentioned by Participant 17. The quality of the water varies in each community and no studies have been done to identify their quality characteristics such as pH, turbidity, chemical composition, and so on.

At the present time, the municipality is working in a "Water Census" project and gathering information to establish a basis for decision making in the future. The water topic is very clear for the participants; this shows the availability of technical capacities in the municipality, unlike Laja and Viacha.

The drilling of wells is not considered as a reliable source of water: in some cases, the water level reduces, and the maintenance is expensive, as mentioned by Participant 16. For this reason, the municipality is focusing on promoting the use of surface water through the implementation of dams and rainwater harvesting, in coordination with the Ministry of Environment and Water (MMAyA in Spanish).

Participant 17 suggested that the management of water resources should be customised by each community, based on their own characteristics such as customs, uses, sources and organisation, to facilitate the implementation of a management plan.

Establishing the cost for water is a challenge; *"it is going to be difficult now because there is no regulation*" says Participant 16. To persuade people to respect any exploitation rate proposed, it will be necessary to explain the reasons and show future scenarios of water availability based on current exploitation rates, as Participant 16 says: *"it is necessary to show how it is going to be in the future, if you say in 20 years your well is going to dry, then they will listen and understand"*.

The most appropriate tool to share information is through workshops, according to Participant 17; this way the participation of the community can be assured and, at the same time, questions can be answered in the moment, as one participant said: *"sometimes one can read the paper and then forget all about it the next day".* There is also a need for education and technical training for gathering information and establishing a monitoring programme that will be part of the "Water Census" project that the municipality is developing.

Findings:

- The municipal government is well organised and innovative.
- The participants are aware of current law and legislation related to water management unlike the other communities.
- There are no exploitation rates or meters in the wells, no infrastructure for distribution.
- People individually do the connections for water supply at their own cost and material.

4.3.4 Other Institutions

Chamber of Industry

The perspective of the industry in the development of a management plan for this aquifer is highly important. The industry sector is one if the main sources of income in the study area, pointed out by Participant 22: of the population in the city, 22 percent work in industries, representing 16 percent of the total national industrial sector in the country (Sanchez Ramos, 2015).

The importance of this sector in the development of both cities (El Alto and La Paz) has been recognised by the Chamber of Industry, promoting the development of the Economic Promotion Act to cover all productive sectors of the El Alto city with incentives for local investment (Sanchez Ramos, 2015).

The Chamber of Industry (CNI in Spanish) is a private institution that represents private entrepreneurs engaged in the manufacturing industry; it promotes the development of the industrial sector by providing training services, advice and technical assistance(Maldonado, n.d.), with the final goal being to strengthen the sector, its competitiveness and the endurance of industries in the country.

In 2004, the CNI introduced the concept of corporate social responsibility (Maldonado, n.d.), which led to development of an Environmental Policy in 2013. These initiatives were created to reduce the impact of the industries on the environment and "*promote the industry to be environmentally sustainable*" (Camara Nacional de Industrias, 2013, p. 5). This policy mainly promotes clean production (PML in Spanish) and energy efficiency, stating that such concepts "*should not be understood [as] an extra cost [of being] bound by the compliance with standards, but as an opportunity to increase the profitability of the industrial enterprise"* (Camara Nacional de Industrias, 2013, p. 9). This is the only initiative developed to contribute to a sustainable use of natural resources in the industry sector. Although it does not identify the water resource by itself, it proposes the creation of Companies of Environmental Services and Management (ESGAs in Spanish). One of the functions of this company, in regard to water resources, will be to develop water consumption audits and in general to identify measures to upgrade technology, and to fund research and training (Camara Nacional de Industrias, 2013)

The current government has implemented many regulations, audit processes and rules towards private industry that has affected their production and competitiveness in relation to water contamination. As a result of these regulatory processes, many industries had to raise their production costs and product prices to cope with fines, and invest in clean technology in order to meet standards. The participants from the CNI highlight that there is an arbitrary management and regulation from the Governorship, Municipal Governments and the Water Company (EPSAS), establishing limits that are general and not specific for each type of industry without coordinating with them, and in most of the cases these limits are not achievable, which leads to fines being applied to the industries. The limits are based on the Environmental Regulations for the Industrial Manufacturing Sector (RASIM) elaborated in 2002, which has not been updated since then. Even though there are yearly monitoring processes and surprise inspections of group with the legal authorities and the water company, participants identified there is no coordination within these institutions, the information and regulation perspective of each institution is different and subject to change due to the influence of political views, as mentioned by Participant 22: "*the political views interfere in the viability of the work between private and public sectors".*

Participants mentioned that it is necessary to have differentiated fines for each industry and these must be established in coordination with the supervisory authority, the water company and the industries individually.

Any regulation or management tool proposed in future must consider avoiding extra costs for industries, as mentioned by Participant 22. Mechanisms such as costly measures to be implemented or straight fines must be avoided; they must consider industry type, production processes, current costs and current development stage of the industry (new, bankrupt, successful, etc.). Participant 21 suggests that measures must have a precautionary focus and not be designed only for the remedial stage. This can be one of the problems with the current regulation, which has a *"sanction focus"* based on the implementation of fines and penalty fees, according to the participants.

The information available is not updated; it is imperative to have data such as an industrial census, identification of the characteristics of the production processes and mapping of industries; these issues have been also recognised in the Environmental Policy of the CNI. There is a lack of planning and infrastructure, such as in industrial areas or "parks", which facilitates the management of water such as exploitation, treatment and discharge. The growth of the industrial sector in the city has been disorganised. The rapid growth of the population in El Alto forced the supply company to rapidly establish an unplanned distribution network and sewerage system to satisfy the demands; now these are sources of contamination. The levels of contamination in the city of El Alto are visible; the solid waste is not managed properly and influences the contamination of surface water and, as recognised in the characterisation of the Aquifer, urban contamination is present in these waters too.

There are a large number of clandestine industries, such as slaughterhouses, soft drink manufacturers and others, that are able to move easily, which makes the audit processes more difficult. These industries are not registered with the NCI. The information will facilitate the establishment of indicators to measure the effectiveness of measures to be taken.

The industries are not considering the non-renewability of the Purapurani Aquifer, mainly because the industries are not informed about this topic. The information has not been shared or explained.

Findings

There is a lack of:

- technical capacities and criteria

- institutional strengthening in the public sector, requiring coordination in the major government institutions such as ministries and vice-ministries
- interpretation of legal documents
- joint work
- monitoring tools and regulation of the exploitation and use of water in the wells.

These steps are required:

- regulation of clandestine industrial activity
- monitoring of xxx
- generation of economic resources from the industries
- a coordinated implementation of measures
- measures established to be based on a comprehensive vision
- establishment of fair parameters for each industry
- strengthening of criteria and initiatives of the industries in corporate social responsibility
- increase education, technical assistance and training
- provision of incentives
- establishment of gradual goals

The unique initiative available for measuring groundwater in the industries is through the permits given by the AAPS, which is mainly a certificate identifying the location and number of wells. Although there is more information behind this regulatory process, it is not shared with or explained to the stakeholders; the participants from the CNI were not involved nor trained in this process, nor in the development of this regulatory action.

Municipal Company of Drinking Water and Sewerage Viacha (EMAPAV)

This company manages deep uptake in Sectors 1 and 2, which make up the main urban area of the Municipality of Viacha, comprising the management of 10 to 11 wells and four wells from Sector 6, near to the main highway that connects El Alto with Viacha, supplying around 9000 users. These wells were already drilled before the Company started functioning; the Company, therefore, does not have the technical studies or information regarding the characterisation of the aquifer. Participant 18 points out that the information is scattered in different institutions and the people responsible are not aware of the location or existence of technical documents or other sources of information.

All the wells have a depth of 70 m, and static levels of 8 m and dynamic levels of 15 m. There are wells exploited by pumping at 14 m^3/s; that rate cannot be exceeded due to the aquifer capacity, even though there are no technical data. In the field, Participant 18 mentioned that once this rate was exceeded, the wells start pumping turbid water and the flow decreased.

At present, EMAPAV is developing a characterisation study of the Viacha aquifer, which is thought to have a hydrological connection with the Purapurani Aquifer; the study will include hydro, chemical and isotopic studies as characterisation methods. This study is a joint effort by this water company, the Ministry of Water of Bolivia and its operative institution, the National Service for Sustainable Basic Sanitation Services (SENASBA in Spanish), among other institutions.

There are no management plans for the exploitation of the aquifer and currently no information is available to develop measures to improve the management of the aquifer.

There is evidence of lack of communication within institutions that are part of the same Ministry, in this case the VRHR and SENASBA: the information developed for the aquifer of Purapurani has not been shared between them, nor have the stakeholders been involved in their management. Evidence of this comes from Participant 18 not being aware or informed that a characterisation study such as the Viacha study had already been developed, nor that EMAPAV was one of the companies involved in the management of the Purapurani Aquifer, besides EPSAS.

The communities manage their water resources based on their uses and customs and have their own water committees established internally, but an issue raised by Participant 18 is that, in most cases, the people on these committees are not qualified for the role and do not have experience in the subject. The main task of the water community representative is to turn the pump on and off, and collect fair rates for electricity payment. The wells are not equipped with meters, so the water price rates are focused only on covering the electricity bills for the pumping equipment. Moreover, there is no technical capacity for solving issues such as pump mechanical problems, and, as a result, they require the assistance of other companies or institutions. This is why Participant 18 highlights the need to develop "friendly techniques" to teach and educate the rural communities in this subject.

There are no further monitoring tasks like gathering data on water levels, water quality, and so on. EMAPAV monitors the wells twice per year in rainy and dry season, "*which is not in accordance with the regulation"* said Participant 18. The regulation suggested that the monitoring times should be established based on the population and other data, but the main issue why the company cannot increase their monitoring processes is lack of money. Participant 18 points out that monitoring activity involves a large amount of expense that is not available in the company. Lack of monitoring implies a lot of risks for the community, such as drinking contaminated water that may affect the health of the members of the community and their animals, which, in most of the cases, are their main source of income.

Another issue acknowledged is that there is no continuity in enforcement of monitoring techniques; the challenge is to develop a mechanism to ensure sustainability despite the political views or change of representatives, a reinforcement of the training programmes and monitoring of community representatives by the municipal governments or water companies.

Regarding the industrial area, EMAPAV is enforcing the regulation developed by the AAPS, identifying and regulating self-supply water systems in the municipality. To be regulated, these wells are required to have meters installed, and are governed by established consumption rates. Participant 18 points out that even this is a good initiative: registering exploited wells is not enough, because there are small industries in the surrounding areas that are not included in this process, mainly because they are not legally registered or "*nobody knows they exist"*.

There is no information regarding the agriculture and livestock sector; the company has not developed this information yet, although these activities are the main source of their income in the municipality.

The regulatory processes and institutes are not defined clearly; the certificates given by the AAPS are not required in any other institution like taxation companies, municipal governments, or chambers of industry, so they are not “needed” for another purpose. Participant 18 suggested that the certificates must be compulsory and requested by any entity involved with the industry.

Participant 18 suggests the use of coercive methods to enforce regulation and ensure the implementation of exploitation rates and limits to achieve certain sustainable standards.

It is important to develop information, update it continually and share it with the community and the stakeholders.

Chapter 5 Results and discussion: Sustainability analysis

The following chapter provides the sustainability analysis framework for the Purapurani Aquifer. As identified in Chapter 3, Section 3.1, the methodology of analysis is based on the identification of:

- Adaptive cycles and nested adaptive systems – Section 5.1
- Failure pathways – Section 5.2
- Critical variables and thresholds – Section 5.3
- Management interventions and institutional arrangements – Section 5.4

The aim of Section 5.1 is to develop the adaptive cycles for the biophysical and social systems identified for the Purapurani Aquifer, based on the four phases of the adaptive cycle: exploitation, accumulation, disturbance/release and reorganisation (Gunderson & Holling, 2002). As a result, there are identified linkages between biophysical and socio-economic systems at different spatial scales.

Sections 5.2 and 5.3 identify failure pathways and critical variables derived from the information gathered in Chapter 4 for the Purapurani Aquifer: main issues, thresholds and critical variables that influence the sustainability of the Aquifer. The analysis was based on the objective to promote a sustainable management, improve current water quality or the ecosystem value of the Aquifer and future groundwater resources in the country.

Finally, Section 5.4 provides an analysis of current management interventions and institutional arrangement that are influencing the exploitation and use of the Purapurani Aquifer. There are also identified concerns regarding these approaches.

5.1 Adaptive cycles and nested adaptive system for the Purapurani Aquifer

The following analysis of adaptive cycles proposes an alternative perspective from the centralised and disorganised water resources management structure in Bolivia. The nested system helps us identify the links and influences between levels and phases at different spatial scales, thus recognising relevant issues resulting from inefficient water management in Bolivia. This methodology is relevant to Bolivian society and its current autonomous management views by addressing social and ecological issues from small-scale or bottom-up planning strategies.

There are three geographical scales to be considered for the sustainable management of the Purapurani Aquifer:

- The Individual/Aquifer level – represented by the social and environmental systems currently dependent on the water supply coming directly from the exploitation of the Purapurani Aquifer.
- The Basin level – represented by the social and environmental systems part of the Katari Basin, which the Purapurani Aquifer is part of, to understand the groundwater–surface interactions.
- The Regional level – represented by a wider Katari Basin, which is influenced by nearby environmental and societal systems in regard to the management of the Purapurani Aquifer.

This level was analysed to identify the influence of other water resources and socio-economic activities in the management of groundwater in the Aquifer and develop a perspective of the overall management of water in the area.

This detail of this section was based on the field data obtained, as well as the information collected and analysed in Chapter 4 of this study. I present the following section discussing main issues identified for the adaptive cycles for each scale summarised in Table 5-1. This table helps to clearly identify the phases for each geographical scale and their components, as well identifying the areas and institutions that directly influence each scale.

For each of the scales identified above, I have explained all the phases of the adaptive cycle individually to create an in-depth understanding of what happens at each level.

5.1.1 The Individual/Aquifer level

As recognised in Chapter 2, the influence of stakeholders in the management of water resources is a key component to achieve sustainability. The success of a management approach or plan relies on the actions and perceptions of the communities and population currently dependent on the water coming from the Aquifer. The first scale of the adaptive cycle examines the relationship between the community and the Purapurani Aquifer. To capture the relationship between the two systems, biophysical system (BPS) and socio-economic system (SES), I have considered on this scale issues such as groundwater use and current exploitation behaviour as the *exploitation phases* for both cycles. The influence of a constant and increasing demand for water from the Purapurani Aquifer leads to an accelerated abstraction of groundwater, which results in a significant decline of groundwater levels and artesian pressure, which leads to the *accumulation phase*. These issues are validated by the study developed for the characterisation of the Aquifer and the interviews developed in the rural municipalities.

The next phase in the adaptive cycle is the *release/disturbance phase*; for this scale, this phase is characterised by contamination of groundwater and evidence of reduced flows in discharge and lowland areas. As mentioned in Section 4.1, contamination of the Aquifer is currently happening as a consequence of sewage intrusion and infiltration of wastewater, as well as contamination from industries, and agricultural activities demonstrated by elevated concentrations of coliform bacteria and Al^{3+}, NO_3^- and NH_4^+.

The final phase of the cycle is the *reorganisation phase*, which represents an opportunity for management interventions for remediation or rehabilitation. This helps us recognise the need to maintain groundwater levels, and hence manage an adequate recharge, and reduce contamination. Activities such as regulating wastewater discharges from industries and households, disposal of solid waste and improving the sewage networks, can significantly improve water quality in the Aquifer. At the present time, management interventions are failing to successfully address these issues, forcing the system to transform into an alternative state – in this case degradation of the groundwater, leading to negative effects in ecosystems and communities dependent on the Purapurani Aquifer. During fieldwork, I noticed that communities have been restricted due to limited water availability and now groundwater quality is decreasing – such is the case for the communities of Laja and Viacha. These rural communities depend on water that can only be extracted from the Aquifer.

Table 5-1 Adaptive cycles for the Purapurani Aquifer at Local/Individual, Basin and Regional Scales

Level	Area considered	Institutions/ stakeholders	Adaptive cycle phase	Socio-economic system (SES)	Biophysical system (BPS)
Individual/Aquifer	- BPS - Purapurani Aquifer delimitation - SES - Population dependent on the Aquifer (Figure 4.9)	- Population dependent on the Aquifer - AAPS - EPSAS - EMAPAV - Other users (Industry, agriculture)	**Exploitation**	Pumping water through EPSAS, EMAPAV, industries and individuals	Abstraction of groundwater from the Purapurani Aquifer
			Accumulation	Reduce availability and quality of the resource for direct users	Decline in groundwater level and artesian pressure
			Release/disturbance	Increasing demand for more water and water security	Reduced flows in lowland streams and increased risk of contamination from land use and infiltration of sewage and wastewater
			Reorganisation	Find new sources and drill more wells, with or without permits	- Maintenance of adequate recharge - Improve water quality
			Resilience/Vulnerability	- Lack of water levels monitoring - No information on water quality in "illegal wells" - No current management interventions direct from users, EPSAS in charge or GAMLP - Draft management plan of the Purapurani Aquifer - Attempt to regulate by AAPS	- Groundwater levels declining - Contamination of groundwater - Water quality decreasing
Basin	- BPS -Katari Basin (Figure 4-8) - SES - Katari Basin (Figure 4-8)	- Rural MG (Pucarani, Laja, Viacha) - MG of La Paz and El Alto - PDCK Directive - AAPS - EMAGUA - EPSAS - Chamber of Industry	**Exploitation**	Increase of population	Infiltration from surface sources (rivers) and rainfall entering the Aquifer within the Basin
			Accumulation	Increase in demand for water for domestic use, agriculture, industry, other uses	Increase of groundwater inflows from river and rainfall infiltration
			Release/disturbance	Decline of water availability and quality	- Aquifer recharge increase levels from groundwater - Contamination of groundwater - Water quality decreasing
			Reorganisation	Development of Basin plans and municipal management plans	Increased aquifer flow in the unconfined aquifer

Level	Area considered	Institutions/ stakeholders	Adaptive cycle phase	Socio-economic system (SES)	Biophysical system (BPS)
			Resilience/Vulnerability	Strategies such as PDCK, PMMAPS, and the regulation approaches from AAPS	Discharge flows influenced by contamination leading to an accumulative contamination in Cohana Bay
Regional	- BPS – Wider Katari Basin (added nearby not yet characterised Basins) - SES - Metropolitan area of La Paz (include municipalities of La Paz and Achocalla)	- GADLP - VRHR (coordination and seek of finance for projects) - MRD - MMAyA - NGOs (financing)	**Exploitation**	Viability for the free exploitation of water as a right to life	Natural and artificial inflows less Abstraction - surface water inflow (rainfall and irrigation runoff) - groundwater inflow (recharge and irrigation leakage) - abstraction from surface and groundwater (Development of new dams at top of the Basin and new wells)
			Accumulation	Indiscriminate and unmonitored or unregulated exploitation of water sources	Water Balance - the accumulation of runoff that generates river flow - inflows from surface and groundwater
			Release/disturbance	Variability of water availability	- the seepage of surface water to groundwater - increase the contamination levels due to infiltration - reduce of surface runoff that recharge groundwater
			Reorganisation	Develop of programmes and project to facilitate water accessibility	Reduced river flow downstream of the reach subject to flow loss
			Resilience/Vulnerability	National strategies: • Mi Riego • Mi Agua • Nuestro Pozo • PDCs	• Degradation of resources in the area • Limited availability of water

5.1.2 The Basin level

At this scale, we can acknowledge groundwater–surface water interactions as the driving force for the cycle. The influence of the Aquifer in the water bodies in the Katari Basin is highly significant and vice versa. As learned in the hydrogeological characterisation, the Aquifer's recharge is highly influenced by rainfall and surface infiltration, establishing the exploitation phase in this adaptive cycle. Rivers such as Seco, Seque and Wilake contribute to the recharge of the Aquifer and are also the main tributaries of the Pallina and Katari Rivers – the main surface water bodies in the Basin. As was estimated, 12.3% of the rainfall in the area actively recharges the Aquifer, increasing groundwater level; this becomes the accumulation phase. For the last two phases of the adaptive cycle at this scale, I have identified the phases of release and reorganisation as the process of recharge, and its influence in Aquifer flow respectively. It has been recognised that in the process of recharge, the Aquifer is highly influenced by contamination from surface water bodies, which influence flow by either increasing or decreasing it.

At this scale, the component of contamination causes a break in the cycle, categorising the system as not resilient. This is based on studies developed by recognising the high levels of contamination of the Cohana Bay in Lake Titicaca (BID, 2013), caused by discharge of water from mostly the Katari River, which receives contaminants from other water bodies in the upper basin (MMAyA & VRHR, 2010). Based on the information gathered (literature reviews and interviews with management institutions) contamination is caused by industries that introduce chemical and heavy metal contaminants and by the area sewage treatment plant, which discharge effluent that has only been partially treated into rivers within the basin.

5.1.3 The Regional level

The area of influence of the basin and the Aquifer, from the point of view of the management of water resources, goes beyond their geophysical limits. Henceforth, this scale includes the municipalities of La Paz, Achachicala, Mecapaca and the Milluni, Choqueyapu and Tuni-Condoriri sub-basins, which are adjacent to the Katari Basin. These municipalities are supplied with water from the Katari Basin, the Tuni-Condoriri sub-basin, from which water is transferred to the basin and areas surrounding Cohana Bay, which are, as was concluded, affected by the contamination of water discharged to Lake Titicaca.

The adaptive cycle for this scale begins with the exploitation phase, which is represented by the natural and artificial inflows coming from the area of this scale, less the abstraction of groundwater, as it is intended to identify the influence of other environmental and socio-economic systems in the Purapurani Aquifer. These processes include surface water inflow coming from rainfall and irrigation runoff, groundwater inflow (recharge and irrigation leakage) and abstraction from surface and groundwater, such as from new dams in the sub-basins and the drilling of new wells in the Purapurani Aquifer. As a result of these activities, the accumulation phase is identified as the water balance in the area, driven by the accumulation of runoff generating river flow, and inflows from surface and groundwater. The contribution of sub-basins to the Aquifer has yet to be quantified, but the interaction of water bodies is represented by the most common issue among scales: contamination.

The contamination of water resources at this scale includes heavy metals and chemicals coming from mining activities in the mountains that surround the area, in addition to the contaminants already identified in Section 4.1. These denote the next stage of the adaptive cycle; the release/disturbance phase represented by processes of seepage of surface water to groundwater and decrease of surface runoff that recharges groundwater. These are influenced by water consumption and environmental processes such as climate change. The decrease of levels in surface water recently caused a major drought at regional scale in November 2016; as a result, La Paz was practically without water and had to ration the little water available (Miranda, 2016). As for the final phase of the cycle – reorganisation – the reduced river flow downstream leading to a break on the cycle. It can be identified that the cycle's vulnerability is the degradation of water resources in the area, leading to limited water availability.

5.1.4 Nested adaptive cycles for the Purapurani Aquifer

It is possible to combine the adaptive cycles from the three different geographical levels into a nested system. As identified in Chapter 3, by nesting the different scales of the cycles we can conclude that the link between Regional–Basin–Individual levels is highlighted by groundwater recharge, availability, and contamination.

The link between the Basin and the Local level is the influence of inflows from the basin into the Aquifer's process of recharge, as well as the influence of demand for the resource. The first relation is between the reorganisation phase at the Basin cycle as input to the reorganisation phase of the Individual/Aquifer cycle. At the same time, this process is also influenced by the Regional level release/disturbance phase*,* considering that nearby sub-basins also contribute to flow rates of surface water bodies. This connection is between the release/disturbance phase from the Regional level and the reorganisation phase from the Basin level. This link also denotes the influence of levels of contamination coming from sources on the broader scale, which will also influence the water quality in the Aquifer, due to infiltration. These sources of contamination were identified in Chapter 4 as mining activities and agriculture in the upper basin.

We can also notice that Individual/Aquifer level release/disturbance phase influences the accumulation phase at Basin level; this shows the connection between water bodies (surface and groundwater) and their influence in the water cycle.

As for the influence of the SES in this nested cycle, the major influence identified was the constant increasing demand for water from the Purapurani Aquifer, which at Basin and Individual/Aquifer levels, determines the sustainability of the cycles. The overexploitation of the Aquifer has driven it to a degraded state that is affecting the quality of life of the communities that depend on it. In the future, population from the Regional level will also affect by this, even though, at this level, society conceives surface water sources for supply as reliable. These surface water sources are currently going through a process of deterioration, influenced by contamination, climate change and unsustainable consumption; as a result, the harvesting of new sources such as groundwater will be required.

It is expected that water demand will increase in the next decades, either for public consumption or industrial/commercial purposes, as identified in Section 4.2. At Individual level, the demand also considers a growth in the industrial sector, specifically in the municipalities of El Alto and Viacha. Based on the outcomes from the fieldwork, it was recognised that industries are extracting groundwater from the Aquifer at unsustainable rates that are not regulated either. Interviewees from the VRHR point out this issue and are concerned about the current situation. Another issue where industries are involved is contamination.

As for the Regional level, the most important influence in the rest of the SES and the BPS is the misconception of the principle of “Water for Life” and the management strategies developed from it. As explored in Section 4.2 of this study, the current approach regarding management of water in Bolivia is based on the concept of water as a human right, and the government has a responsibility and obligation to provide access to it. In addition to the autonomous management approach, this concept has been misunderstood by the rural and indigenous communities. This was identified also in the interviews with rural communities and their representatives; they consider that access to water must be provided instantly as a response to a demand. Many of the interviewees were not aware of the need to develop environmental and socio-economic studies before any exploitation activity. They feel supported by this concept and the authority granted by the new institutional reforms. This has driven the government to develop programmes such as “MiAgua” (My Water), “MiRiego” (My Irrigation), and “Nuestro Pozo” (Our Well) in response to the demands for water from the rural communities. Specifically, “Nuestro Pozo” promotes the drilling of wells in remote communities as an immediate response to water demand, the implications of which can be foreseen in the community of Laja. According to the interviews, the community well water flow and pressure has been reduced, and water is available only in limited quantities and for intermittent periods. The well was drilled due to a formal request from the Municipal Governments (MG). Currently the management and maintenance of the well is the responsibility of the MG.

The influence of institutional arrangement and management intervention at Regional Level is highly significant for the assessment and implementation of management tools to address sustainability issues. The sustainability issues recognised in the system will be analysed as part of the next section: failure pathways.

5.2 Failure pathways

Water as a biophysical system is affected by multiple pathways. The identification of failure pathways helps us determine processes that can cause cycles to turn into degradation, and cause vulnerabilities in the connections between BPS and SES, as seen in Chapter 3. The failure pathways identified for the Purapurani Aquifer are based on Table 5-2, which also shows their links to the different types of sustainability issues.

At the Regional Level we can identify the following failure pathways:

- **9. Climate change** – Based on information gathered and evidence collected in the fieldwork, the influence of climate change in the region has shown its effects on water resources. Climate change has regionally variable effects on hydrology. The pathway is identified due to the reduction of surface water flows that reach the Aquifer and lowland streams at the reorganisation phase in the BPS, causing a disturbance in the water availability in the release phase of the SES system at the same level.

8. Collapse of trade networks – Water scarcity is masked in industrial processes and food production**.** This pathway is represented by the increasing exploitation of groundwater by the industrial sector and agricultural activities in the region and its influence in the water availability at the Basin level, and vice versa (accumulation to release/disturbance phase).

Table 5-2 Failure Pathways for the Purapurani Aquifer

GEOGRAPHIC SCALE	TYPE OF SUSTAINABILITY ISSUE			
	TYPE 1 Biophysical maintenance	TYPE 2 Socio-economic impact on Biophysical	TYPE 3 Biophysical impact on socio- economic	TYPE 4 Socio-economic maintenance
Region		9. Climate change		8. Collapse of trade networks
Society	1.Water availability	2. Impact of water use	3. Natural disasters	4. Institutional arrangements
Individual	*Local natural resource depletion*	*Local environmental degradation*	6. Disease	5.Individual commitment

At the Basin level, we can identify the following failure pathways:

- **4. Institutional Arrangements** – The maintenance of the socio-economic system, at this level, is driven by management approaches to address water availability developed by the institutions responsible. At this level, we can identify strategies such as PDCK, PMMAPS, and the regulation approaches from AAPS that are currently failing in the management of the Aquifer, as well as current environmental and water legislation. Responsibilities and roles are not clearly assigned within institutions, municipal governments and the community.
- **3. Natural disasters** – As a result of climate change and overexploitation, the basin is exposed to floods and droughts. Floods have not been recorded yet, but it is possible that in the future, areas near rivers and lakes will experience them. This is a consequence of rapid glacial melting, the main source of inflows for surface water bodies. On the other hand, droughts have already affected the area. For this reason, it is necessary to manage extremes such as these by developing responses and mitigation measurements.
- **2. Impact of water use** – We can identify water resource deterioration due to human mismanagement at Basin level and also recognise it as *local environmental degradation* at Individual/Aquifer level. The increasing demand for water at these levels has led to an overexploitation of the Aquifer and surface sources in the Basin. We can conclude that there is no responsibility for the exploitation or disposal of the water resource.
- **1. Water availability** – This is influenced by extraction, recharge and contamination, affecting small-scale agriculture, livestock and consumers adversely in rural areas where water treatment is not available. This failure pathway can be recognised at the Individual/Aquifer level as *local natural resource depletion*; as evidenced by the case in the north-west of the Aquifer where there is no access to basic services such as drinking water and sanitary sewerage. This issue was highlighted by the authorities from the MG of Laja and Pucarani.

At the Individual/Aquifer level, we can identify the following failure pathways:

- **6. Disease** – The alteration of water quality can cause negative impacts on consumers. The levels of contamination identified in the Aquifer are not lethal, but can affect the health of the consumers in the long term. The connection is made between the reorganisation phase from the BPS to the release/disturbance phase at the SES. As was identified by the process of recharge, the Aquifer has been receiving contaminants from surface water infiltration and intrusion. As noted, the disposal of sewage often does not meet the standards set out in the current regulation, contaminating the surface water, which infiltrates the Aquifer.
- **5. Individual commitment** – This pathway represents the commitment that society has leading to a transformation or maintenance of the societal organisation. Jenkins (2015b) considers that to achieve sustainable water management there is a need for individual commitment to a sustainable, ethical management of water. There is no current evidence of such in the SES at the Individual/Aquifer level; based on the information gathered mainly through the interviews, water user and direct consumers (industries) were not engaged in the process of planning or management. Influencing individual behaviour through motivation and education, and commitment can be used to promote a sustainable use of groundwater from the Aquifer.

5.3 Critical variables and thresholds

The next step of the sustainability analysis is the identification of critical variables and thresholds. As seen in Chapter 3, the critical variables are key parameters on failure pathways, and thresholds are the tipping points that can change the state or function of a socio-ecological system (Jenkins, 2015c). The critical variables and thresholds for the management of the Aquifer are described in Table 5-3.

We can identify three common critical variables across the three levels of the nested system: groundwater recharge, contamination, and availability. Analysis for thresholds of critical variables in relation to these vulnerabilities does not appear to have been undertaken. As can be seen in Table 5-3, the only thresholds related to water resources are water quality standards for water consumption and for discharge after treatment. This would make the current water quality for groundwater the basis for setting the thresholds, as well as values of recharge percentage from rainfall that has been identified in the characterisation of the Aquifer in 2015.

However, in order to prevent further deterioration of the Aquifer, the goal will be to develop a management strategy to promote sustainable and regulated exploitation. As was reviewed in Subsection 2.3, international management approaches, such as that in Canterbury, New Zealand and the EU groundwater framework, gives positive feedback regarding the implementation of allocation limits and the establishment of groundwater-specific quality standards.

It can be also concluded that in order to comply with current water management visions in Bolivia, water accessibility must be ensured. This will represent a major constraint to management approaches and plans where previous environmental and socio-economic studies are necessary. It is necessary to introduce concepts of co-governance and co-management within the national government, Municipal Government and the community. This would make water accessibility a threshold.

Table 5-3 Critical variables and thresholds

Level	Critical variables	Thresholds
Region	Seepage rate from surface water inflows	Not determined
	Water quality in surface bodies for consumption	Bolivian Water Standards*: - NB-512 *List of parameters in Appendix D
	Water quality for discharge after treatment	Bolivian Water Standards*: - RMCH * List of parameters in Appendix D
Basin	Amount of seepage from the river	Not determined
	Amount of rainfall over the unconfined Aquifer	Not determined
Aquifer	Demand for drinking water	Not determined
	Groundwater quality with respect to drinking water standards	Bolivian Water Standards*: - NB-512
	Groundwater levels and pressures	Not determined
	Allocation limits to water supply	Not determined
	Allocation limits to other uses	Not determined

5.4 Management interventions and institutional arrangements

Management interventions are actions to enhance the resilience of system (Jenkins, 2015c). This section collects existing management interventions and identifies those that should be implemented to achieve sustainability. As recognised in Chapter 3, management interventions can address each phase of the adaptive cycle, as can be seen in Figure 3-5. Each level of the nested system (Region, Basin, Aquifer) will be addressed by considering each SES and BPS and their connections to the other levels. It is important to mention the significance of a first analysis of the current situation (Chapter 4) in environmental and socio-economic systems in order to propose these management interventions as we can see in Figure 3-5. I consider that the following management interventions I propose will reduce significantly the current overexploitation effects on the Purapurani Aquifer and prevent further degradation of the system.

On the other hand, I consider it relevant to include the identification of institutional arrangements as part of this section, because institutional arrangements are necessary to implement management interventions. As we have seen in Chapter 3, institutional arrangements have the following characteristics: facilitation of integration of functions to meet societal/environmental needs and management of conflict among different interests (Jenkins, 2015c).

Based on information provided by the interviewees from the VRHR and AAPS, and the information collected in Section 4.2, we recognised that currently there are two main management interventions at Regional Level, focused on reducing the pressure of current groundwater exploitation activities (exploitation phase); these are the PNC and the 2013 and 2014 RARs developed by the AAPS. Although the PNC does not have the power to develop and implement regulatory management tools, its objective is to develop and promote sustainable use of water resources in the Basins across the country, by developing and identifying sustainable approaches, the Draft Sustainable Management Plan for the Purapurani Aquifer, for example.

In the case of the RARs, as management tools proposed by the AAPS (regulatory authority), they have a regulatory character in addressing exploitation activities. As seen in Section 4.2, RAR AAPS No. 04/2014 establishes the responsibility of the AAPS to provide authorisation/permits for water exploitation through SARH (surface and groundwater sources) for public and private sectors, as well as to establish the conditions and costs of its operation. As for the RAR AAPS No. 004/2013, it establishes a standard price of 0.42 USD/m^3 for industrial purposes. It is important to notice that this water price is subject to change, depending on the industry category that would be established by the AAPS. For the regulation of each SARH, they are entitled to fill in and submit a Regularization Form available in Appendix D. In Section 2.3, we can see a section specific to the regulation of the exploitation of groundwater bodies; the data requested is the drilling method, operation start date, material, depth and diameter of tubing, type of coating, static and dynamic levels, pump depth and power, and finally pumping rates in units of m^3 per month. Section 3 also requires the SARH to identify the purpose for the exploitation of the water resource.

Although these regulatory tools have been approved, not every SARH complies with them, as was confirmed by the VRHR and the AAPS through the interviews. It was also recognised in the interviews that these RARs were not shared with the VRHR, MGs and rural communities, reducing their effectiveness of its implementation.

As for future management interventions, the AAPS has proposed the implementation of a Strategic Triennial Sustainability Plan for Water Sources (PESFA), meant to be implemented by EPSAs in the country. PESFAs will provide hydrogeological information regarding water resources managed by an EPSA, and a proposal for the development of a project or study to promote their sustainability. The management tool contemplates issues such as availability, quality, ecosystem protection and risks related to the exploitation of the resource. Furthermore, a qualitative scale of assessment of the behaviour towards the protection and sustainability of the water sources has also been suggested, where groundwater is also considered and evaluated. Even though this tool provides substantial and important reforms to the current management of groundwater, it fails to request the participation of the community in any project or study to be developed by EPSAs. This management tool is under revision and does not have a deadline for its implementation, as recognised during the interviews.

As for the institutional arrangements, the country's constitution establishes the need to create a competent authority of water resources for the implementation of these tools, but, to date, none has yet been established; until then AAPS is the institution responsible. As a result, we recognise the need for the government to establish this authority so that responsibilities and roles are clearly appointed. It is also necessary to establish mechanisms to promote social participation in the development of water projects according to the Popular Participation Law seen in Section 4.2 of this study.

Another regional management intervention is the programme "Nuestro Pozo" discussed in Section 4.2, which address legacy issues as discussed previously (accumulation phase). Although this programme complies with the concept of "Water for Life" promoted by the national government, it does not consider sustainability concepts for the exploitation of groundwater use. Here we identify the need to regulate this programme under sustainability objectives in order to ensure the availability of the resource for future generations and avoid situations such as the one the Laja government is currently experiencing. The institutional arrangement for the implementation of this programme is the creation of the EU-Wells which, importantly, is under the management of the MRD, which has no water development units, unlike the MMAyA. This issue was raised by the participants from the VRHR.

There are currently no management interventions that promote the rehabilitation of the resource or increase the resilience of the system; these are interventions for the release/disturbance and the reorganisation phases of the cycle. Furthermore, there are no management interventions that assess the failure pathways identified for the level: climate change and collapse of trade networks.

It can be concluded that it is necessary to develop management approaches and policies, at national government levels, similar to the RMA in New Zealand and the EU Water Framework Directive, to serve as environmental/water management and regulatory frameworks, to be consulted by lower levels and guide the development of groundwater management strategies, such as regional policies or plans, and develop regulatory tools according to the regions' characteristics. As per the international experiences review in Chapter 2, it is also necessary to create an institution with (or assign to a current water-related institution) the responsibility for the administration of these management approaches and policies, as seen in the groundwater approaches of China and USA.

For the Basin level, it can be recognised that current management interventions also involve regulation from the AAPS cited earlier, and the implementation of the PNC through the PDCK. As predicted, the management interventions repeat the cycle from Regional level, addressing legacy issues and reducing pressure on the resource.

We can highlight at this level the development of information through the PDCK and the proposal of an institutional arrangement for the management of the Basin through the Institutional Platform of the PDCK, as illustrated in Figure 4-13. In addition, an institutional organisation is proposed, shown in Figure 5-1, by identifying institutions to be considered in the management of the water resources of the basin and a first approach to formally recognise the participation of the community, users and stakeholders dependent on the water resources within the Basin.

It is intended to develop a future sustainable management approach for the Basin, where the stakeholders and the institutions are included as part of the development process. Based on the communications and information discussed in Chapter 4, it can be concluded that these structures are yet to be implemented, even though the PDCK was established in 2011.

As positives outcomes, the PDCK developed the information necessary to address the rehabilitation of adverse effects and increase the resilience of the BPS of the Basin through the development of a National Basin Plan (PDC) as an operative tool for a progressive implementation of Integrated Water Resources Management. In addition, there is an initiative to develop an information system and a database, as example for other Basins in the country. Moreover, we can consider the influence of private institutions in the development of this information, because these are the main sources of finance. All things considered, the institutional arrangements are also the ones considered at the Regional Level.

In conclusion, there are no management interventions that address all the failure pathways identified at this level: water availability, impact of water use, and natural disasters.

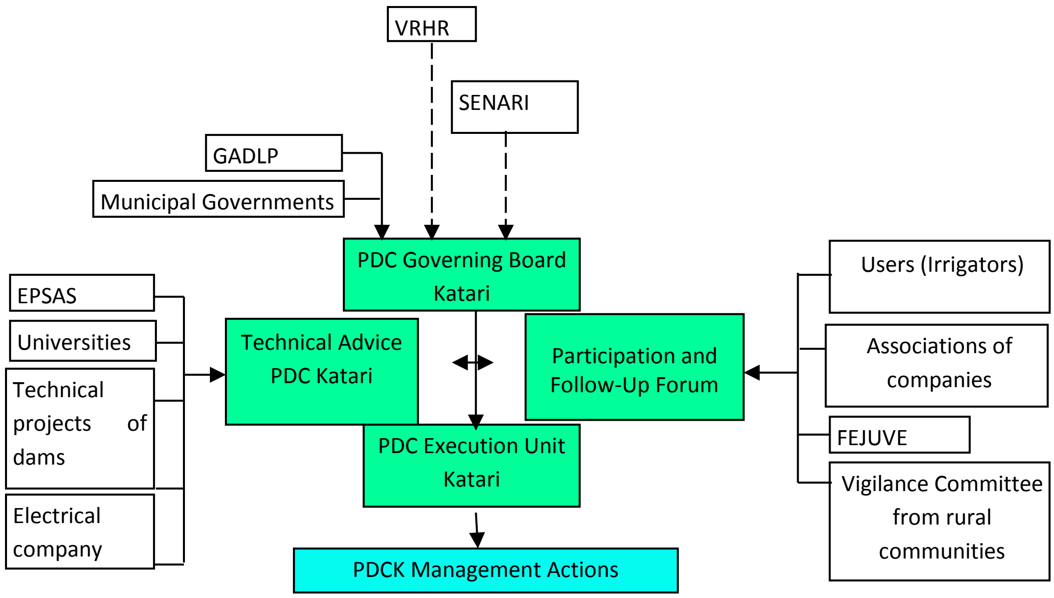

Figure 5-1 Institutional arrangements PDCK, adapted from MMAyA et al., 2015, p. 69

As suggestions for management interventions at this level, experiences from western USA, China and Australia, were set out as examples to be replicated in the Katari Basin. The approaches taken in these countries promote a management of groundwater resources at regional or basin scales, where regional council or state governments oversee the development and implementation of management strategies. The approaches show a more decentralized approach with clear responsibilities and objectives for these institutions. For the implementation of these management arrangements, it will be necessary to build capacities and improve the education of the stakeholders involved in the Basin. The effectiveness of the international approaches reviewed in Chapter 2 found that social involvement and support from regulatory tools was imperative.

At Individual/Aquifer level, we can conclude that there are no current regulations related to its exploitation, use or protection.

At the exploitation phase of the Aquifer's cycle, we can determine that there is no current management to reduce the pressure on the resource. Although the AAPS has slowly promoted the implementation of regularisation reform, mentioned in Chapter 4 and earlier in this section, the mechanism is not yet compulsory. This is the only regulatory measure approach in the Aquifer. It is important to recognise that this reform fails to address sustainability management options, thus it can be considered more as a registration approach rather than regulatory. Although the AAPS regulates the current EPSAS in charge of the exploitation of the Aquifer (EPSAS and EMAPAV), they have either regulations or approaches to reduce the overexploitation, but they have complied with the registration suggested by the AAPS. In the case of industries and SARHs in the Aquifer, the AAPS registration approach has not yet been implemented, and in some cases they are not aware of this mechanism. We can point out a very important institutional arrangement at this stage, the necessity to establish an institutional unit in charge of socialisation and capacitation of stakeholders. There are no further management approaches at these institutions.

It was also discovered that urban and rural municipal governments do not have legal regulations to intervene against the type of exploitation and indiscriminate use of water currently happening in the Aquifer. Even so, they have the authority to propose regulation mechanisms given by the Law of Administrative Decentralization (Chapter 4). It is worth mentioning that the GAMEA and GAMLP (urban MGs) have undertaken an intervention process over EPSAS, in order to "reassign" responsibilities so the municipal governments will be responsible for the management of water resources within their territories. As seen in Chapters 2 and 4, EPSAS currently provide water services for La Paz and El Alto, mainly based on water resources located in other municipalities' territories; this is the case for El Alto, which is supplied by surface sources located in La Paz. Interviews refer to this issue as a matter of "Water Justice"; this concept will be considered over the management suggestions section.

As for the rest of the phases identified for the Aquifer cycle, there are no current management measures in place, thus the failure pathways of *Local natural resource depletion* and *Local environmental* degradation are not addressed either. In the case of the failure pathway of disease the regulation of discharge and water quality was identified as the only approach to protect water resources, mainly surface water. Although the regulation does not include water standards for groundwater, it promotes the protection of water that serves as the main recharge source of the Aquifer. However, based on the information gathered, interviews and fieldwork, the effectiveness of this regulation is questionable. The levels of current Aquifer contamination, as well as surface water, explored in Chapter 4, shows that these measures lack periodic inspection and monitoring activities to ensure their application.

For the next failure pathway, individual commitment, it was identified that the process of socialisation and capacity building is limited and, in some cases, inefficient. The evidence for this conclusion is the socialisation process developed by the VRHR for the characterisation of the Aquifer. Personnel responsible for contacting the community at the initial stages managed to communicate effectively with the community, but failed to provide updates regularly about the stages of the project. This was one of the main issues identified during fieldwork; communities were not aware of the objectives of the Aquifer's characterisation, and furthermore, that this project had already been concluded. Some authorities were not aware of the existence of the project because they were newly stated. The same issue was identified in relation to communication with stakeholders, such as industries, municipal governments and the AAPS, which were not involved in the project, as was verified during the interviews.

In Chapter 2, participation involvement was identified as playing a key role in the implementation of management approaches at the international scale; thus it is imperative that the community and stakeholders participate actively in the development of management approaches.

Based on the information analysed previously, and international experiences, we can suggest the following management interventions in order to promote a sustainable management for the Purapurani Aquifer, summarised in Table 5-4.

Table 5-4 Management interventions for the sustainable management of the Purapurani Aquifer

System	Issue	Management Intervention	Observations
BPS	Groundwater quantity (recharge and abstraction)	- Predicts groundwater level due to climate variation. - Develop consents to give legal entitlement to use water. - Consent constraints on location and abstraction rates. - Groundwater zone allocation limits. - Consent review for cumulative effects of overexploitation. - Management of climate variability and effects of abstraction. - Alternative consent regimes. - Constraints for new bores. - Establish sustainable yields. - Protection of sources of recharge. - Assessment of artificial recharge methods.	- Specific rules both in the process of exploitation of the resource as well as in the aspect of regulating the activities of private users. - Constraints on further takes from the groundwater zone, and possible review of existing takes. - Extraction limited to recharge with adequate water available to sustain groundwater-dependent ecosystems.
	Groundwater contamination (quality)	- Surface and groundwater quality standards updated. - Reinforce mechanism for water quality regulation implementation.	- Water quality standards and regulation need to be updated considering current conditions of the system and the influence of the SES.
	Groundwater protection	- Water pricing. - Processes to encourage water efficiency improvements. - Water allocations subject to environmental requirements.	- Different pricing rates depending on use. - SARHs establish different rates previously evaluated by a regulatory institution. - Efficiency improvements for access to reliable water. - Reward mechanisms that recognise stakeholders that comply with sustainable management objectives.
SES	Management organisation	- Establish management at groundwater zone scales. - Zone management programmes to address water use efficiency. - Management of cumulative effects on groundwater bodies	- Takes may be restricted when the effective allocation of groundwater exceeds the groundwater zone allocation limit.

		and dependent ecosystems.	
	Develop Information	- Develop an information system.	- Regarding the generation of information, the country does not have a national water resources information system that allows adequate planning of the same. To date, the access and availability of information on water resources is deficient and incomplete.
	Social participation, capacity building and education	- Open and active participation of users in water management (social participation and decentralization) where the problems and approaches of indigenous peoples and communities are priorities. - Social participation (strengthening, support and promotion to the articulation of community systems, cooperatives and associative organisations of community systems, as well as legal recognition of customs). - Water justice.	- Develop an educational and communication programme as part of a management strategy.
	Legal instruments	- Legal and solid legal framework focused solely on groundwater management. - Establish specific regulations.	

Chapter 6 Conclusions: Towards sustainable management of the Purapurani Aquifer, management options and recommendations

The overall aim of this study was to provide a sustainability analysis for the use and management of groundwater resources in Bolivia, based on the Purapurani Aquifer in the La Paz Region, by identifying critical management issues and suggesting management interventions. Within this context, the specific objectives were to:

- Collect groundwater information and data available for the Purapurani Aquifer and its current management to develop a sustainability analysis.
- Generate information regarding the current use of the Aquifer and management perceptions of the authorities, stakeholders and community representatives, to develop an overview of the current situation of the Purapurani Aquifer.
- Develop a comprehensive literature framework based on information and data gathered regarding hydrogeological, legal and socio-economic aspects of the Purapurani Aquifer.
- Identify and analyse failure pathways in the management of the Aquifer in order to provide management interventions for current and future issues of groundwater exploitation.
- Suggest sustainable management measures for the management of groundwater resources in Bolivia, based on the Purapurani Aquifer.
- Produce an informative document for stakeholders and communities with the purpose of promoting sustainable use of groundwater in the Purapurani Aquifer and informing them about the current state of the Aquifer.

The following paragraphs address the specific objectives described above while highlighting the main issues and recommendations identified in the study.

Information availability and consistency

The process of collecting information confirmed the previous issues of scattered and limited sources of information regarding the Purapurani Aquifer. Reports and studies were collected from various sources: from government to private organisations such as NGOs. Even though the information was regarding one main topic – the Purapurani Aquifer – documents were difficult to find, and the process of requesting information was also tedious and slow. This issue was also recognised over the fieldwork and the interviews. Requesting available time with public institutions such as municipal governments and central government took long periods of time, in contrast to private organisations, where the response was close to immediate.

We can conclude that the process of collecting information is difficult due to a sparsity and lack of categorisation of information, which also shows the need to establish a public institution focused only on information management, such as the example of the New Zealand government's National Monitoring System (NMS). The creation of such an institution would also address the issue of accessibility to information, as mentioned above. As viewed in the international groundwater management experiences in Chapter 2, the accessibility to information plays a key role in the management of water resources. The effectiveness of management measures is supported by strong communication mechanisms that educate and inform the community and stakeholders of current management interventions and future management options. The information gathered was focused on three main subjects: hydrogeological, legal and socio-economic information influencing the management of the Purapurani Aquifer.

Observations in hydrogeological information

Reports regarding hydrogeological information were found to be interrelated and complementary to each other; although some issues regarding methodology and gaps of information were also identified, however, mainly in the report of the hydrogeological characterisation of the Aquifer. These issues were based mainly on a lack of updated information for the formulation of results: data used for calculations such as recharge rates are mainly estimated, and, most of the time, do not correctly reflect the current situation of the aquifer. This observation was also made in the development of information in groundwater systems in Spain, where dated information compromised the development of management interventions.

Another issue was identified in the water quality analysis. Water quality information is inconsistent between sampling periods of 2013 and 2014, although the periods of sampling are correlative; some wells sampled in 2013 were not sampled in 2014 and vice versa. Furthermore, concentration analysis also varied; we can point out the difference in parameters analysed in 2013 from 2014, for example, TDS, Eh, Al^{3+}, BOD5, COD, Fe_{total} and Mn_{total}. Moreover, there are no further explanations of such differences between sampling periods. These observations were also identified in Chapter 4, Section 4.1. There were also further observations regarding composition and language of this report. The language is mainly scientific and technical, and not easy to understand for those who have no engineering or science background. Concepts and methodologies used in the characterisation of the Aquifer were not previously explained, making the identification of key information more challenging. Henceforth, it is necessary to develop reports that integrate science with the common language, making technical reports, such as this one, easy to read and comprehend by people from all kinds of backgrounds: engineers, social workers, stakeholders, and rural and urban communities, among others.

One of the aims of this characterisation study was for it to be replicated in other groundwater bodies in Bolivia, but the information provided regarding methodologies and tools used are, in some areas, confusing and complicated, hindering the replicability of the study. Here we identified the need to develop guidelines for the characterisation of aquifers in Bolivia that will be provided with starting points for gathering information necessary to the hydrogeological characterisation of groundwater. The example provided by Foster and Loucks (2006b) through their summary of hydrogeological tools to guide groundwater development and management can be followed; see Table 2-1 of this study. By providing a baseline for developing these studies, future issues can be avoided regarding the comparability of results between aquifers, basins and regions. Results will be normalised and will address objectives established with a common goal: the sustainable management of groundwater resources.

Observations in socio-economic and legal information

Regarding legal and socio-economic information, the main observation for both topics is the widely scattered sources, as mentioned before. Information regarding these topics is more accessible and comprehensive, in contrast to hydrogeological information. Furthermore, it was possible to identify that this type of information is managed separately from hydrogeological reports, which influences the final results by failing to provide a complete overview and understanding of the groundwater system. Under those circumstances, it is essential to promote a new integrated view of management of water resources, where we recognise the importance and influence of legal and socio-economic information in the maintenance and management of a natural resource. This issue was recognised in groundwater management strategies of Canterbury, New Zealand, where social data has been acknowledged as necessary to develop a complete understanding of land uses, consumption, social trends and local knowledge.

The information collected through interviews helped to understand and consider current management perceptions and approaches regarding the Purapurani Aquifer. This process provided new knowledge significant to this study; introducing stakeholders and the community views and suggestions' in the proposals for management interventions. As main outcomes from this process, it is necessary to develop communication spaces with the community and stakeholders, and promote educational activities and capacity building for the purpose of introducing the concept of sustainable management in groundwater.

As a result of this information-gathering process, the study achieved its third objective: to develop a comprehensive literature framework for the Purapurani Aquifer. Chapter 4 and Appendices illustrate this result. The information gathered was analysed, compiled and organised in order to provide understanding and an informative section that helped in identifying issues and opportunities in the current situation of the Aquifer and will consequently serve as an informative document for stakeholders and communities with the purpose of promoting the sustainable use of groundwater in the Purapurani Aquifer and providing information about the current state of the Aquifer, as intended by the last objective of the study.

Unsustainable management of the Purapurani Aquifer

The information gathered in previous stages achieves the next objective. Chapter 5 achieves what was proposed: to identify and analyse failure pathways in the management of the Aquifer in order to provide management interventions for current and future issues of groundwater exploitation. Through the methodology of sustainability analysis proposed by Jenkins, I was able to identify the connection between the hydrogeological and socio-economic characteristics within the Purapurani Aquifer based on the identification of adaptive cycles. The methodology also promotes the development of a nested adaptive cycle system, where I was able to identify the connections of the Aquifer scale to Basin and Regional scales, and the resilience of each system.

As a result of the development of the cycles for each scale and the nested system, I identified that the current exploitation and contamination in the Purapurani Aquifer has led to a degradation of the cycle, which also affects other scales. It was also recognised that these effects were mainly a consequence of activities developed at Basin and Regional scales. Such is the case of the contamination of surface water due to lack of sewage treatment, and inefficient management of wastewater in the Region of La Paz, which are main sources for recharge in the Aquifer. The study revealed that management of groundwater must recognise the influence and connection of this resource to other natural resources and the environment. Furthermore, the influence of socio-economic activities in the degradation of the Aquifer and the nested system was also recognised. The most important examples include an increase in water demand, unsustainable use of groundwater, and a lack of appropriate management and regulation. Under these circumstances, the current Aquifer nested system was identified as unsustainable.

Aquifer degradation and resource depletion

In order to change the current situation, those failure pathways that cause the system to shift to an alternative degraded state were identified. As mentioned previously, two main failure pathways were identified: *local environmental degradation* through water contamination, and *local natural resource depletion* through the identification of an overexploitation of the Aquifer. Other failure pathways identified were climate change, and collapse of trade networks, at Regional Scale; and water availability, impact of water use, natural disasters, and institutional arrangements at Basin Scale. It is important to mention that the identification of these failure pathways assist us in the process to recognise the influence of a biophysical system to a socio-economic system and vice versa, and to identify management measures.

Lack of regulation mechanisms for groundwater management

The next step of the methodology led to the identification of critical variables and thresholds that help to assess the current status of the biophysical system. As a result of this section, it was easy to corroborate what was concluded in early stages: the system lacks a regulation mechanism for groundwater management. I was able to identify that current enforced legislation only addresses water quality parameters and discharge limits, but there is no evidence of approaches to regulate exploitation rates of either surface or groundwater sources. Despite current government approaches ensuring quality of life to their inhabitants being nationally promoted, they lack sustainability concepts. It was found that current legislation and regulation is focused on covering current water demand without considering future demands. One demonstration of this is the groundwater development programme of "Nuestro Pozo" (My Well), which supplies the population's water demands in rural communities with a prompt response based on well drilling, without previous studies.

Management recommendations

What recommendations can this research give regarding previously suggested management interventions to successfully achieve a sustainable management of groundwater resources in Bolivia? Based on all of the observations made at each stage of the sustainability analysis, I was able to identify management interventions to address these failure pathways and critical variables with the intention of implementing the concept of sustainability in the Purapurani Aquifer. It is worth mentioning that these management interventions were suggested after considering and incorporating current management approaches for the Purapurani Aquifer. The main results can be summarised in four groups: (a) groundwater availability and protection; (b) social participation, capacity building and education; (c) institutional arrangements and legal instruments; (d) developing information and monitoring mechanisms.

The management interventions suggested for group (a) comprises activities necessary to manage groundwater quantity and quality such as identifying groundwater allocation limits, the development of consent, constraints on location and abstraction rates and water allocations, subject to environmental requirements, among others. To implement these, there is the need to provide specific rules for each process of exploitation, and differentiate water pricing for each activity. Helpful approaches used internationally include the gathering of assessments to identify groundwater allocation zones, set allocation limits, and set safe yields while promoting sustainable management of the resource, such as is the case in Canterbury, New Zealand.

The suggested management interventions of groups (b) and (c) are interrelated. As identified in international experiences, in order to engage social participation in management processes, it is necessary to deliver institutional arrangements that can provide communication spaces for capacity building for stakeholders and decision makers, and further educating users and the community. Through the information gathered and the interviews developed in the fieldwork, these approaches are seen to be highly necessary, especially in rural communities and for direct users of the Purapurani Aquifer development. Results from interviews show that communities lack knowledge regarding groundwater systems, concepts and understanding of the consequences of current use and exploitation. Developing an educational and communication program as part of the management strategy for the Aquifer is suggested. Many successful strategies had the active participation of stakeholders, institutions, community, and, most importantly of all, water users, in support of better management. Educating water users and building capacities is crucial for sustainability, as stated by Alley et al. (1999): “Knowledge about groundwater is an indisputable prerequisite for a sustainable use of water as a valuable natural resource”.

Based on the current legal and legislative framework, as previously mentioned, it is imperative to develop or adjust current regulations to be focused solely on groundwater management. As seen in international management experiences, regulation tools are highly significant in promoting and ensuring the implementation of management mechanisms and guaranteeing the sustainability of this resource.

For the final group of management suggestions, I identified as highly significant the importance of focusing efforts to develop information regarding hydrogeological characterisation, but there are other tools that must be included in the overall analysis. Socio-economic and legal information should also be prioritised in order to develop a complete overview of an aquifer. As previously mentioned, the influence of these sectors in the processes of both developing and implementing management measures is significant and directly influences both the effectiveness and achievement of sustainability goals. As for the monitoring activities, it is necessary to advise the effectiveness of management measures and, in future, improve and update these measures continuously.

In conclusion, the sustainability analysis developed for the Purapurani Aquifer helped me to identify an adequate, sustainable management approach for the Aquifer, applicable for the characteristics of the area. Future management strategies must provide allocation limits for groundwater exploitation, based on abstraction rights, ownership and regulation; such limits will be subject to continuous revision, while promoting ongoing monitoring and social participation. The immediate establishment of water authorities is also recommended at every spatial scale to elaborate management strategies that acknowledge the importance of water users’ participation, and understand their traditions and customs in relation to the management of the Purapurani Aquifer.

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APPENDICES

Appendix A Information sheet and written consents for interviews

Waterways Centre for Freshwater Management
Telephone: +64 221902706
Email: estef.arteagavaldivia@pg.canterbury.ac.nz

Groundwater resources management, a sustainable policy approach for the Purapurani Aquifer, Bolivia

Information Sheet

My name is Estefania Arteaga; I am a master's student in the Waterways Centre for Freshwater Management at the University of Canterbury. My research is proposes a policy approach for the sustainable management of groundwater resources based on the concept of social-sustainable development, in order to provide the government of Bolivia a long-term strategy to manage groundwater resources effectively considering future demands and environmental challenges by building the knowledge and capacities in the institutions in charge of its management and the community. My study will consider the Purapurani aquifer as a baseline to develop the management policy as an example for future management plans.

If you choose to take part in this study, your involvement in this project will be informal interviews that will last between thirty minutes and an hour and will be audio recorded. This research has no known risks.

Participation is voluntary and you have the right to withdraw at any stage without penalty. You may ask for your raw data to be returned to you or destroyed at any point. If you withdraw, I will remove information relating to you. However, once analysis of raw data starts on June 30th it will become increasingly difficult to remove the influence of your data on the results.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: your identity will not be made public without your prior consent. To ensure anonymity and confidentiality, your identity or personal information will not be disclosed in any publication that may result from the study. Notes that are taken during the interview will be stored in a secure location. A thesis is a public document and will be available through the UC Library.

Please indicate to the researcher on the consent form if you would like to receive a copy of the summary of results of the project.

The project is being carried out as a requirement for the Masters Degree of Water Resources Management by Estefania Arteaga under the supervision of Professor Bryan Jenkins who can be contacted at bryan.jenkins@canterbury.ac.nz. He will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return it signed and completed to Estefania Arteaga.

Waterways Centre for Freshwater Management
Telephone: +64 221902706
Email: estef.arteagavaldivia@pg.canterbury.ac.nz

Groundwater resources management, a sustainable policy approach for the Purapurani Aquifer, Bolivia

Consent Form

☐ I have been given a full explanation of this project and have had the opportunity to ask questions.

☐ I understand what is required of me if I agree to take part in the research.

☐ I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.

☐ I request that any information or opinions I provide will be kept confidential to the researcher and the supervisor and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.

☐ I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after five years.

☐ I understand the risks associated with taking part and how they will be managed.

☐ I understand that I am able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.

☐ I understand that I can contact the researcher :
Estefania Arteaga (estef.arteagavaldivia@pg.canterbury.ac.nz) or supervisor:
Professor Bryan Jenkins (bryan.jenkins@canterbury.ac.nz) for further information.
If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)

☐ I would like a summary of the results of the project.
(The results of the project will be made available to the participants by providing copies distributed via email or paper)

☐ By signing below, I agree to participate in this research project.

Name:______________________________Signed:____________________________Date:________________

Email address: estef.arteagavaldivia@pg.canterbury.ac.nz

You can return this form to researcher Estefania Arteaga

Appendix B Comparison of fluctuating levels of wells located in the Purapurani Aquifer

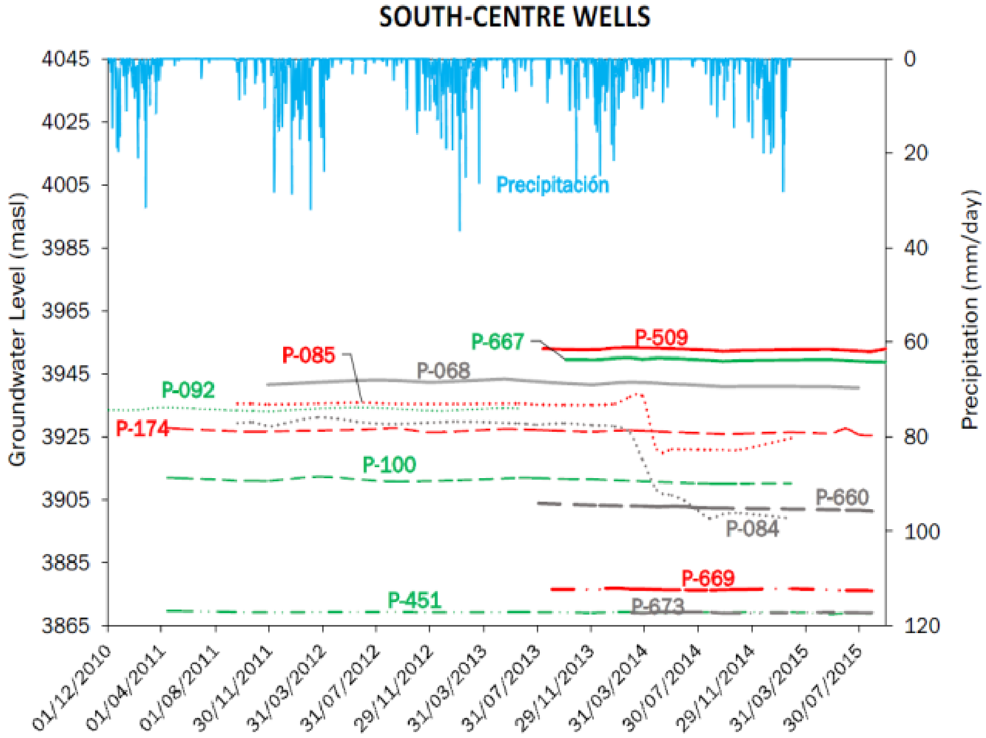

Figure B-1 Comparison of fluctuating levels of south-centre wells. From Geodatabase of VRHR – PDCK, 2016, Annex D.

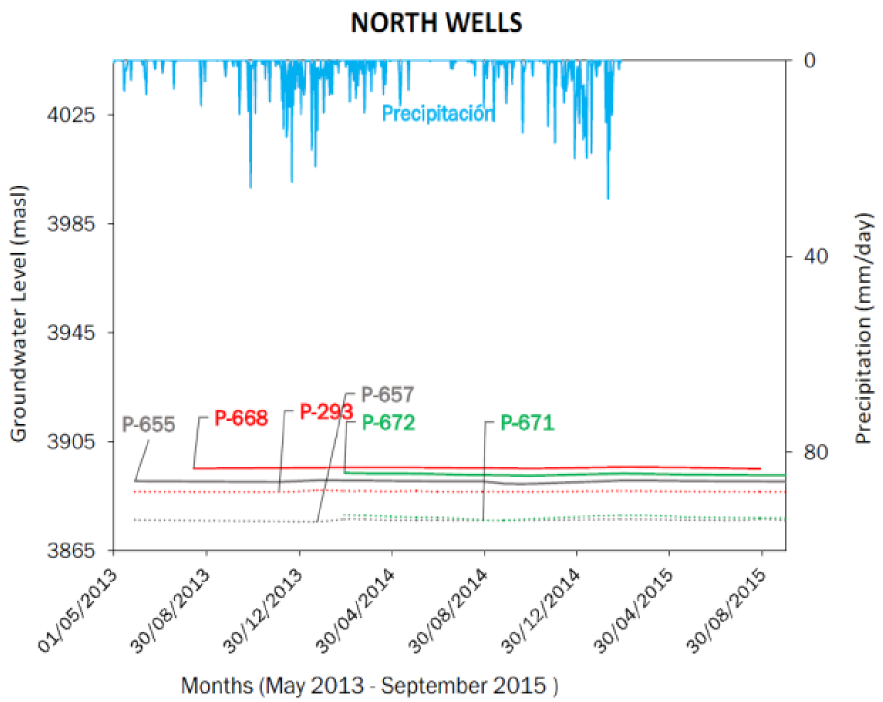

Figure B-2 Comparison of fluctuating levels of north wells. From Geodatabase VRHR – PDCK, 2016, p. Annex D

Appendix C Water quality results in the Purapurani Aquifer

Table C- 1 Inorganic concentrations in mg/L for the different monitoring wells, sampling season July 2013

	Type	T	EC	TDS	pH	OD	Eh	Ca^{2+}	Na^{+}	Mg^{2+}	K^{+}	Al^{3+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	NO_3^{-}	NO_2^{-}	NH_4^{+}	SiO_2	BOD5	COD
		(°C)	(µS/cm)	(mg/l)		(mg/l)	(mV)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
R-01	River	7.0	172.2	111.9	7.9	- -	-58.1	17.4	3.3	3.9	1.1	3.0 [1,2,3]	32.0	33.5	2.0	10.5	0.001	1.8 [1,2,3]	6.4	5.1 [1]	22
R-02	River	8.3	1232.0	655.1	3.8 [1,2,3]	5.4	193.0	97.0	3.4	44.4	1.5	11.5 [1,2,3]	0.1	434.1 [1,2]	3.7	19.6	0.011	2.3 [1,2,3]	19.4	7.5 [1]	29
P-653	PM	12.7	294.1	155.2	6.2	3.9	22.2	21.9	9.0	9.2	2.7	1.1 [1,2,3]	18.2	31.8	20.2	37.5 [1]	0.001	1.9 [1,2,3]	16.2	18.9 [1]	72 [1]
P-231	PM	13.3	400.2	211.8	6.4	6.4	8.0	21.7	15.6	11.6	3.9	1.4 [1,2,3]	32.3	65.0	14.1	19.2	0.002	1.7 [1,2,3]	22.4	14.6 [1]	61 [1]
P-221	PM	13.8	516.5	276.3	6.1	2.9	23.6	33.1	10.9	14.0	3.7	1.2 [1,2,3]	32.1	48.8	27.5	50.2 [1,2,3]	0.002	1.9 [1,2,3]	13.4	15.2 [1]	58 [1]
P-339	PM	14.6	328.0	173.2	6.5	4.9	4.7	19.8	12.3	11.0	2.0	1.0 [1,2,3]	33.6	26.5	28.9	45.1 [1,2]	0.003	1.9 [1,2,3]	11.2	4.8	19
P-517	PM	13.3	245.4	130.0	6.9	4.5	-20.3	14.3	10.3	7.9	0.9	1.0 [1,2,3]	39.1	22.2	15.8	22.9 [1]	0.004	1.9 [1,2,3]	12.2	4.9	20
P-518	PM	14.1	201.2	107.7	7.4	4.8	-47.3	11.1	9.5	6.8	1.0	1.0 [1,2,3]	25.4	11.0	14.8	35.7 [1]	0.007	2.0 [1,2,3]	12.2	6.2	26
P-519	PM	12.8	154.5	81.6	7.4	5.5	-47.3	10.0	7.9	4.5	1.2	1.6 [1,2,3]	30.9	10.3	13.3	19.1	0.010	2.6 [1,2,3]	13.6	0.2	< 0.5
P-071	PM	14.3	274.1	144.5	7.3	3.5	-38.2	19.2	22.7	3.5	2.2	0.9 [1,2,3]	117.4	24.7	10.0	5.4	0.001	0.04	14.4	0.3	1
P-175	PM	14.3	288.6	152.1	6.9	3.9	-17.0	19.5	26.0	3.9	2.7	0.8 [1,2,3]	117.4	26.6	11.7	11.8	0.002	0.1 [1]	17.8	< 0.2	< 0.5
P-177	PM	13.8	207.5	109.3	7.1	5.4	-31.6	10.3	10.6	5.7	2.4	0.8 [1,2,3]	58.3	24.3	11.0	13.1	0.001	0.1 [1]	19.6	< 0.2	< 0.5
P-188	PM	14.0	146.2	77.0	7.2	4.6	-34.1	17.9	8.6	3.3	1.6	0.9 [1,2,3]	36.4	22.8	10.6	19.2	0.001	0.2 [1]	16.4	8.1 [1]	1
P-091	PM	14.2	140.5	74.2	7.2	5.9	-35.5	18.2	8.8	2.8	1.8	0.7 [1,2,3]	36.4	25.0	8.5	14.3	0.002	0.1 [1]	20.4	< 0.2	< 0.5
P-179	PM	14.3	121.4	63.9	7.4	3.5	-44.8	17.9	8.1	1.7	2.1	0.9 [1,2,3]	40.5	25.0	6.0	9.1	0.002	0.1 [1]	25.0	3.9	14
P-180	PM	14.0	206.7	108.8	7.1	4.9	-29.0	17.4	7.9	7.3	1.8	1.1 [1,2,3]	43.2	22.8	14.5	21.4 [1]	0.002	0.2 [1]	19.6	1.3	5
P-081	PM	14.4	118.8	62.6	7.1	4.1	-28.4	13.9	4.9	2.6	1.4	1.0 [1,2,3]	35.0	13.6	4.7	13.6	0.002	0.1 [1]	19.2	3.9	16
P-182	PM	13.9	118.3	62.4	7.3	1.5	-40.5	13.1	7.8	1.4	1.8	0.8 [1,2,3]	41.9	17.3	3.0	7.3	0.002	0.2 [1]	32.2	< 0.2	< 0.5
P-184	PM	14.1	130.6	69.0	7.1	3.7	-30.6	13.6	8.2	1.8	2.4	1.5 [1,2,3]	43.2	20.1	3.7	10.2	0.002	0.1 [1]	35.0	< 0.2	< 0.5

P-099	PM	13.1	214.2	112.9	6.9	2.9	-16.2	15.1	13.1	3.4	3.9	$0.9_{1,2,3}$	48.7	21.1	9.6	12.5	0.002	0.2_{1}	19.0	< 0.2	< 0.5
P-098	PM	13.9	287.0	151.3	6.6	3.2	-4.1	20.9	12.9	7.0	3.0	$0.7_{1,2,3}$	43.2	28.5	16.5	31.6_{1}	0.001	0.1_{1}	22.8	< 0.2	< 0.5
P-094	PM	14.2	178.2	93.9	7.0	4.8	-26.4	13.5	7.5	5.1	2.3	$0.7_{1,2,3}$	32.3	21.5	12.3	21.1_{1}	0.000	0.2_{1}	24.8	0.3	1
P-172	PM	14.8	308.5	161.2	6.8	5.7	-9.4	18.0	12.6	12.3	1.1	$0.8_{1,2,3}$	62.5	25.6	22.1	31.6_{1}	0.004	0.2_{1}	16.6	< 0.2	< 0.5
P-288	PM	13.9	289.7	152.3	6.8	4.7	-13.3	29.3	10.1	10.3	1.8	$0.8_{1,2,3}$	32.3	40.5	26.4	$47.6_{1,2}$	0.005	0.2_{1}	16.0	0.3	0.6
P-289	PM	16.4	393.4	207.2	6.5	3.3	2.6	29.3	11.3	15.7	2.4	$0.6_{1,2,3}$	44.6	30.8	34.7	$60.4_{1,2,3}$	0.003	0.2_{1}	16.2	< 0.2	< 0.5
P-338	PM	14.8	233.0	123.6	7.0	4.9	-21.6	15.7	9.8	8.4	1.4	$0.5_{1,2,3}$	15.8	23.1	20.1	43.8_{1}	0.003	0.2_{1}	17.8	< 0.2	< 0.5
P-506	PM	14.0	350.5	184.9	7.0	4.8	-26.6	38.8	22.0	10.0	13.5	$0.4_{1,2,3}$	121.5	43.5	29.4	28.8_{1}	0.003	0.2_{1}	39.6	0.5	2
P-271	PM	15.2	185.8	98.6	6.9	5.8	-21.4	23.0	6.5	6.4	2.3	$0.5_{1,2,3}$	87.1	12.0	14.6	13.3	0.002	0.2_{1}	20.6	0.2	0.6
P-102	PM	14.0	154.5	81.4	7.3	4.2	-43.6	17.3	8.0	3.6	2.0	$0.4_{1,2,3}$	72.1	8.4	3.7	9.6	0.003	0.2_{1}	23.4	0.5	1.3
P-107	PM	14.1	188.3	99.2	7.5	5.0	-55.0	26.3	9.1	3.3	3.1	$1.2_{1,2,3}$	87.6	19.5	3.8	8.1	0.001	0.2_{1}	36.0	0.2	0.5
P-504	PM	12.6	179.5	94.6	7.8	5.5	-71.1	17.7	8.9	3.4	3.2	$0.4_{1,2,3}$	76.6	11.8	3.5	9.2	0.003	0.2_{1}	31.6	0.5	1.5
P-224	PM	12.7	221.0	120.7	7.3	4.7	-38.4	28.3	6.8	5.5	3.7	$0.3_{1,2,3}$	70.5	52.3	3.4	4.0	0.002	0.2_{1}	36.6	0.7	2.7
P-194	PM	14.8	246.2	134.7	7.1	4.5	-23.5	19.1	26.0	3.2	3.6	$0.6_{1,2,3}$	87.8	45.4	11.2	3.6	0.003	0.2_{1}	44.0	0.4	0.9
P-195	PM	12.7	259.5	141.6	7.5	2.1	-46.1	24.4	9.0	6.7	4.7	$0.4_{1,2,3}$	64.4	53.7	3.4	4.6	0.001	0.2_{1}	29.4	0.6	2.2
P-208	PM	13.5	479.2	264.0	7.0	2.7	-19.6	42.5	24.0	15.8	6.6	$0.4_{1,2,3}$	161.3	63.2	25.3	16.2	0.003	0.2_{1}	26.2	< 0.2	< 0.5
P-125	PM	11.0	188.9	103.2	7.0	3.5	-18.1	21.4	8.4	5.9	2.3	$0.4_{1,2,3}$	59.6	48.0	7.2	1.2	0.003	0.2_{1}	21.0	14.5_{1}	14
P-277	PM	13.7	242.1	132.5	7.4	3.0	-14.1	32.7	6.9	8.3	2.6	0.1	43.5	92.4	2.4	1.1	0.002	0.2_{1}	30.8	< 0.2	< 0.5
P-661	PM	14.5	362.3	198.4	7.0	3.8	-19.3	32.4	21.0	9.6	4.3	0.024	111.0	73.0	6.9	3.8	0.001	0.2_{1}	41.6	5.8_{1}	22
P-662	PM	11.9	353.6	193.6	7.1	2.8	-26.4	38.1	13.9	7.0	2.8	0.001	94.3	54.3	5.5	6.3	0.001	0.2_{1}	23.4	31.3_{1}	122_{1}
P-663	PM	13.6	321.4	175.9	7.3	2.7	-35.0	35.4	9.0	8.4	7.3	0.2	102.0	51.3	6.1	14.7	0.003	0.2_{1}	27.4	1.8	6
P-300	PM	12.1	143.9	78.7	6.7	3.7	-2.9	26.3	4.1	3.1	1.5	0.02	58.3	35.2	4.5	9.2	0.001	0.2_{1}	23.2	< 0.2	< 0.5

P-659	PM	15.5	238.8	131.4	7.0	4.6	-18.4	19.7	12.1	6.1	4.4	0.3[1,2,3]	83.9	11.3	8.7	9.5	0.002	0.2[1]	28.6	< 0.2	< 0.5
P-316	PM	15.0	125.2	68.8	7.4	5.1	-43.5	13.1	8.7	2.5	1.7	0.3[1,2,3]	53.8	11.3	3.2	8.5	0.002	0.2[1]	22.2	< 0.2	< 0.5
P-314	PM	12.9	203.5	108.4	7.0	5.3	-13.1	26.4	10.4	5.0	3.6	0.1	54.2	55.6	5.5	8.8	0.002	0.2[1]	25.6	< 0.2	< 0.5
P-664	PM	13.7	308.3	163.0	6.5	5.7	-0.8	22.0	10.8	10.2	2.3	0.2	57.6	30.7	22.7	12.3	0.001	0.2[1]	21.4	< 0.2	< 0.5
P-296	PM	10.9	85.5	45.7	6.3[2,3]	6.1	7.8	9.8	4.1	3.4	1.1	0.1	23.4	23.8	2.4	5.9	0.002	0.2[1]	15.6	< 0.2	< 0.5
P-665	PM	13.3	82.7	44.8	6.4[2,3]	5.0	6.7	12.4	3.3	2.5	1.0	0.1	18.4	30.2	2.6	4.6	0.003	0.2[1]	18.6	< 0.2	< 0.5
P-666	PM	11.1	78.9	42.5	6.7	5.8	-11.5	9.4	7.0	2.4	1.9	0.1	17.0	31.8	3.0	6.8	0.005	0.2[1]	31.0	< 0.2	< 0.5
P-514	PM	8.0	156.3	84.5	7.1	6.3	-31.8	22.1	5.6	4.2	2.0	1.6[1,2,3]	29.7	56.2	3.4	3.6	0.018	0.2[1]	29.6	< 0.2	< 0.5
P-667	PM	- -	352.0	228.8	7.5	- -	- -	29.8	51.0	6.2	4.7	0.024	134.3	72.4	18.7	5.1	0.005	0.2[1]	32.6	< 0.2	< 0.5

PM: Monitoring well

(green)	Exceed Class A RMA
(yellow)	Exceed NB 5-12
(blue)	Exceed WHO water supply limits
(red)	Exceed all three limits
(orange)	Exceed Bolivian regulation
(magenta)	Exceed NB and WHO

Table C- 2 Inorganic concentrations in mg/L for the different monitoring wells sampling - May 2014

	Type	T	EC	pH	OD	Ca^{2+}	Na^{+}	Mg^{2+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	NO_3^{-}	NO_2^{-}	NH_4^{+}	SiO_2	Fe_{total}	Mn_{total}
		(°C)	(µS/cm)		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
P-071	PM	14.0	278.0	7.4	5.2	13.5	37.0	5.1	2.2	61.9	24.1	36.1	5.4	0,003	0.03	23.6	0.2	0.1
P-081	PM	14.4	117.4	7.6	5.6	12.3	7.3	3.8	1.4	47.0	12.1	5.9	13.7	0,003	0.03	27.3	0.2	0.1
P-085	PM	12.1	250.0	6.8	6.2	15.0	23.7	6.7	3.1	61.0	36.5	18.3	17.8	0,007	0.03	28.4	0.2	0.1
P-091	PM	13.6	147.1	7.5	5.9	9.6	12.6	5.0	1.9	46.3	9.9	12.6	15.9	0,003	0.03	31.0	0.2	0.1
P-094	PM	14.7	192.2	7.5	6.3	15.5	10.4	6.7	2.5	33.2	13.7	19.1	24.3	0,003	0.03	31.4	0.2	0.1
P-097	PM	14.5	113.4	7.4	7.0	10.9	9.9	2.6	3.1	57.6	8.2	4.0	8.3	0,003	0.04	37.0	0.3	0.1
P-099	PM	12.7	227.0	7.0	6.7	13.0	24.7	4.3	4.4	60.8	25.6	14.9	18.6	0,003	0.02	24.7	0.3	0.1
P-102	PM	14.1	155.3	7.6	6.2	15.8	11.5	5.0	2.2	75.2	15.3	6.8	8.2	0,004	0.02	28.4	0.2	0.1
P-125	PM	11.7	177.5	7.8	5.6	18.2	11.9	6.3	2.6	88.4	20.8	8.6	1.2	0,004	0.03	30.7	0.3	0.1
P-171	PM	15.6	237.0	7.4	5.9	19.6	12.7	9.2	2.4	66.3	11.9	26.3	24.3	0,003	0.03	32.9	0.2	0.2
P-172	PM	14.5	316.0	7.6	6.4	25.9	18.7	14.4	1.1	82.3	30.4	28.9	40.8	0,002	0.01	38.1	0.3	0.2
P-174	PM	14.7	205.0	0.0	5.8	19.2	6.9	9.7	2.8	62.7	17.2	17.5	21.5	0,003	0.22	37.7	0.2	0.1
P-175	PM	14.1	362.0	7.3	6.5	17.6	58.9	5.5	3.2	181.7	18.3	21.9	10.5	0,003	0.03	31.4	0.2	0.2
P-177	PM	14.0	206.0	7.5	6.0	17.3	18.7	6.3	2.5	75.5	16.1	15.1	12.9	0,003	0.04	28.8	0.2	0.2
P-179	PM	14.4	102.3	7.8	5.6	10.1	12.6	3.1	2.1	47.9	9.3	8.9	10.2	0,003	0.03	22.1	0.2	0.1
P-180	PM	15.2	214.0	7.2	5.6	18.3	11.1	8.8	1.9	62.6	14.4	19.5	24.5	0,003	0.02	29.2	0.2	0.2
P-182	PM	14.2	120.7	7.3	5.9	9.7	14.0	2.8	2.8	54.8	14.7	4.3	8.8	0,004	0.03	19.5	0.2	0.1
P-188	PM	13.6	151.2	7.5	6.5	13.3	11.7	4.4	1.6	42.9	7.6	16.3	19.9	0,003	0.02	27.3	0.2	0.1
P-195	PM	12.4	283.0	8.1	6.2	26.9	16.7	8.5	5.9	96.2	60.1	4.9	4.0	0,003	0.12	21.4	0.2	0.1
P-221	PM	13.3	480.0	6.5	5.7	38.9	14.7	15.0	3.8	57.1	60.9	38.1	48,6[1,2]	0,003	0.05	25.1	0.2	0.2
P-224	PM	12.5	229.0	7.7	6.2	25.6	12.0	8.9	5.4	102.8	41.5	5.6	3.4	0,004	0.03	13.6	0.2	0.1
P-231	PM	14.8	411.0	7.2	6.4	28.4	31.8	13.3	4.7	85.1	82.8	17.1	19.6	0,003	0.05	44.4	0.2	0.1
P-271	PM	15.5	158.5	7.7	5.9	16.1	8.5	5.9	1.9	61.7	14.6	12.5	9.4	0,002	0.01	28.8	0.3	0.1
P-272	PM	14.0	397.0	7.2	5.7	34.6	22.1	10.9	6.2	99.0	39.1	25.3	28.9	0,003	0.04	41.8	0.3	0.2
P-287	PM	10.8	545.0	7.0	6.5	42.0	30.8	19.6	2.7	114.6	15.4	70.4	53,9[1,2,3]	0,006	0.11	20.7	0.3	0.1
P-288	PM	16.7	304.0	6.9	5.2	25.3	13.9	12.2	1.8	56.9	9.8	37.6	39.3	0,003	0.0	22.5	2.7	0,15[1,2,3]
P-289	PM	15.2	126.9	7.5	6.2	12.3	9.3	4.7	1.0	40.5	7.2	13.0	18.3	0,003	0.0	29.2	0.3	0.1
P-293	PM	12.5	230.0	7.1	5.2	26.3	10.6	8.9	1.3	101.6	32.3	4.7	8.4	0,005	0.1	27.7	0.2	0,13[1,2,3]
P-296	PM	10.5	94.3	6.8	7.2	12.9	7.9	3.0	1.6	60.1	9.0	2.5	5.0	0,004	0.0	21.4	0.3	0.1

P-300	PM	12.0	155.6	7.4	6.8	29.0	6.1	5.4	1.7	105.4	10.9	6.0	8.1	0,002	0.0	34.0	2.4	0,13$_{1,2,3}$
P-316	PM	13.2	132.4	7.7	6.5	13.0	13.7	3.8	1.8	68.0	11.0	5.7	8.6	0,003	0.0	33.6	0.3	0.1
P-338	PM	15.8	266.0	7.1	5.7	17.5	13.0	10.0	1.6	35.0	11.5	29.5	42.5	0,003	0.0	28.4	0.2	0,2$_{1,2,3}$
P-339	PM	13.9	342.0	7.0	6.0	26.7	17.7	12.8	2.1	49.8	23.4	41.5	48,6$_{1,2}$	0,006	0.0	21.0	0.2	0,2$_{1,2,3}$
P-451	PM	13.4	150.7	13.4	5.4	15.6	9.6	4.5	1.9	73.7	7.7	6.6	8.2	0,005	0.0	21.8	0.3	0,2$_{1,2,3}$
P-451*	PM	11.5	133.4	7.9	4.6	15.6	15.3	3.9	4.8	91.4	8.5	6.4	8.1	0,003	0.0	27.3	0,35$_{1,2,3}$	0,13$_{1,2,3}$
P-510	PM	13.0	1289.0	7.7	4.5	30.8	246,8[1,2,3]	7.4	4.3	356.2	147.7	99.1	21.3	0,023	0.4	11.0	0.4	0,4$_{1,2,3}$
P-514	PM	14.5	319.0	7.9	3.2	28.6	23.7	8.7	4.3	84.0	53.5	28.2	3.8	0,242	0.7	12.5	0.3	0,16$_{1,2,3}$
P-517	PM	13.0	225.0	7.7	6.0	19.4	12.7	8.1	0.8	62.7	19.5	20.3	18.7	0,002	0.0	27.3	2.9	0,15$_{1,2,3}$
P-518	PM	13.3	226.0	7.1	6.4	18.2	13.3	8.1	1.0	29.5	15.8	22.5	41.4	0,004	0.0	27.3	0.3	0,2$_{1,2,3}$
P-519	PM	12.4	143.3	7.6	6.3	12.6	10.5	4.8	1.3	42.0	6.6	16.9	17.9	0,005	0.0	31.4	0.3	0,2$_{1,2,3}$
P-523	PM	13.7	150.3	7.7	6.0	14.0	6.4	5.1	1.5	44.5	15.9	12.1	0.0	0,004	0.1	27.7	0,33$_{1,2,3}$	0,15$_{1,2,3}$
P-525	PM	16.6	306.0	9.0	4.1	27.9	16.7	9.9	2.7	54.7	43.6	34.0	20.7	0,012	1.8	6.6	0,31$_{1,2,3}$	0,15$_{1,2,3}$
P-636	PM	16.7	147.4	7.8	5.7	15.9	11.8	5.2	2.8	76.3	12.0	9.3	6.7	0,002	0.0	43.3	2.7	0,15$_{1,2,3}$
P-660	PM	15.3	112.4	7.6	5.9	16.2	9.5	4.1	1.5	69.7	7.9	4.7	6.3	0,011	0.1	65.5	0,32$_{1,2,3}$	0,15$_{1,2,3}$
P-661	PM	4.6	401.0	8.0	7.9	29.6	49.3	9.7	5.9	132.7	120.1	11.3	2.9	0,010	0.0	34.0	2.8	0,14$_{1,2,3}$
P-662	PM	12.2	204.0	7.1	6.0	29.5	59.9	9.7	4.9	303.0	19.7	13.5	6.1	0,005	0.1	33.6	0,33$_{1,2,3}$	0,17$_{1,2,3}$
P-664	PM	15.3	328.0	7.4	5.5	34.0	16.7	11.2	2.8	92.8	39.7	33.6	10.7	0,002	0.0	31.0	2.8	0,15$_{1,2,3}$
P-665	PM	13.8	84.2	6.7	5.7	11.1	5.9	3.2	1.5	51.4	8.2	1.9	4.9	0,004	0.1	28.1	3.0	0,15$_{1,2,3}$
P-666	PM	12.2	80.8	7.2	6.9	9.6	7.1	2.4	1.7	48.8	5.5	1.6	7.6	0,003	0.0	31.0	0,31$_{1,2,3}$	0,15$_{1,2,3}$
P-667	PM	15.0	422.0	7.3	5.6	33.2	12.9	20.3	2.9	84.8	28.9	38.4	58.5	0,050	0.1	25.5	2.7	0,17$_{1,2,3}$
P-668	PM	12.8	201.0	7.1	6.3	17.1	20.7	5.6	2.4	102.5	21.8	7.5	3.0	0,006	0.1	35.8	0,31$_{1,2,3}$	0,16$_{1,2,3}$
P-674	PM	5.7	1209.0	7.8	6.4	13.2	40.8	4.8	3.9	142.2	18.3	12.7	1.5	0,008	0.1	25.1	2.6	0,14$_{1,2,3}$
P-675	PM	8.2	251.0	7.2	6.4	77.1	104.1	51.1	24.0	390.0	299.3	20.4	14.3	0,015	0.0	31.8	1.9	0,12$_{1,2,3}$
P-677	PM	12.1	316.0	6.9	6.7	23.4	13.3	10.9	3.1	38.7	38.2	24.3	29.4	0,005	0.1	30.7	2.3	0,14$_{1,2,3}$

*Monitoring piezometer

Exceed Class A RCHC
Exceed NB 5-12
Exceed WHO water supply limits
Exceed all three limits
Exceed Bolivian regulation
Exceed NB and WHO

Appendix D Water quality regulations applicable to Bolivia

Regulation on Water Pollution (RMCH)

Table D - 1 Regulation of Water Pollution - Maximum admissible values of parameters in receptor bodies

Parameters	Unit	Carcinogens	Class "A"	Class "B"	Class "C"	Class "D"
pH			6.0 to 8.5	6.0 to 9.0	6,0 to 6,9,0	6,0 to 9,0
Temperature			+/-3°C of receptor	+/-3°C of receptor	+/-3°C of receptor	+/-3°C of receptor
Total dissolved solids (TDS)	mg/L		1000	1000	1500	1500
Oils	mg/L	NO	Absents	Absents	0,3	1
BOD5	mg/L	NO	<2	<5	<20	<30
COD	mg/L	NO	<5	<10	<40	<60
NMP	N/100ml	NO	<50 and <5 at 80%	<1000 and <200 at 80%	<5000 and <1000 at 80%	<5000 and <5000 at 80%
Parasites	N/L		<1	<1	<1	<1
Colour mg Pt/l	mg/L	NO	<10	<50	<100	<200
Dissolved oxygen	mg/L	NO	>80% sat.	>70% sat.	>60% sat.	>50% sat.
Turbidity	UNT	NO	<10	<50	<100<2000***	<200-10000***
Sediment solids	mg/L – ml/L	NO	<10mg/L	<30mg/L – 0.1 ml/L	<50mg/L – <1ml/L	100 – <1ml/L
Aluminium	mg/L		0.2 c. Al	0.2 c. Al	0.2 c. Al	0.2 c. Al
Ammonia	mg/L	NO	0.05 c. NH_3	1.0 c. NH_3	2 c. NH_3	4 c. NH_3
Antimony	mg/L	NO	0.1 a.Sb	0.01 a.Sb	0.01 a.Sb	0.01 a.Sb
Arsenic total	mg/L	YES	0.05 c.As	0.05 c.As	0.05 c.As	0.1 c.As
Benzene	µg/L	YES	2.0 c.Be	6,0 c.Be	10,0 c.Be	10,0
Barium	mg/L	NO	1,0 - 0,05 c. Ba	1.0 c. Ba	2.0 c. Ba	5.0 c. Ba
Beryllium	mg/L	YES	0.001 c. B	0.001 c. B	0.001 c. B	0.001 c. B
Boron	mg/L		1.0 c. B	1.0 c. B	1.0 c. B	1.0 c. B
Calcium	mg/L	NO	200	300	300	400
Cadmium	mg/L	NO	0.005	0.005	0.005	0.005

Cyanide	mg/L	NO	0.02	0.1	0.2	0.2
Chlorides	mg/L	NO	250 c. Cl	300 c. Cl	400 c. Cl	500 c. Cl
Copper	mg/L	NO	0.05 c. Co	1.0 c. Co	1.0 c. Co	1.0 c. Co
Cobalt	mg/L		0.1 c. Co	0.1 c. Co	0.1 c. Co	0.1 c. Co
Hexavalent chromium	mg/L	YES	0.05 c. Cr total	0.05 c. Cr^{+6}	0.05 c. Cr^{+6}	0.05 c. Cr^{+6}
Trivalent chromium	mg/L	NO		0.6 c. Cr^{+3}	0.6 c. Cr^{+3}	0.05 c. Cr^{+6}
Tin	mg/L	NO	2.0 c. Sn	2.0 c. Sn	2.0 c. Sn	2.0 c. Sn
Phenols	µg/L	NO	0,3 C, Fe	0,3 C, Fe	1,0 C, Fe	1,0 C, Fe
Fluorides	mg/L	NO	0,6 - 1,7 c. F	0,6 - 1,7 c. F	0,6 - 1,7 c. F	0,6 - 1,7 c. F
Phosphate total	mg/L	NO	0.4 c. Orthophosf.	0.5 c. Orthophosf.	1.0 c. Orthophosf.	1.0 c. Orthophosf.
Magnesium	mg/L	NO	100 c. Mg	100 c. Mg	150 c. Mg	150 c. Mg
Manganese	mg/L	NO	0.5 c. Mn	1.0 c. Mn	1.0 c. Mn	1.0 c. Mn
Mercury	mg/L	NO	0.001 Hg	0.001 Hg	0.001 Hg	0.001 Hg
Lithium	mg/L		2.5 c. Li	2.5 c. Li	2.5 c. Li	5 c. Li
Nickel	mg/L	YES	0.05 c. Ni	0.05 c. Ni	0.5 c. Ni	0.5 c. Ni
Nitrate	mg/L	NO	20.0 c. NO3	50.0 c. NO3	50.0 c. NO3	50.0 c. NO3
Nitrite	mg/L	NO	<1.0 c.N	<1.0 c.N	<1.0 c.N	<1.0 c.N
Nitrogen total	mg/L	NO	5 c. N	12 c. N	12 c. N	12 c. N
Lead	mg/L	NO	0.05 c. Pb	0.05 c. Pb	0.05 c. Pb	0.05 c. Pb
Silver	mg/L	NO	0.05 C. Ag	0.05 C. Ag	0.05 C. Ag	0.05 C. Ag
Pentachlorophenol	µg/L	YES	5.0	10.0	10.0	10.0
Selenium	mg/L	NO	0,01 c Se	0,01 c Se	0,01 c Se	0,05 c Se
Sodium	mg/L	NO	200	200	200	200
Floating solids			Absent	Absent	Absent	<ret. Film 1 mm 2
Sulphates	mg/L	NO	300	400 c, SO_4	400 c, SO_4	400 c, SO_4
Sulphur	mg/L	NO	0.1	0.1	0.5	1.0
S.A.A.M. (Detergents)	mg/L		0.5	0.5	0.5	0.5
Tetrachloroethane	µg/L	NO	10	10	10	10

Trichloroethane	µg/L	YES	30	30	30	30
Carbon tetrachloride	µg/L	YES	3	3	3	3
2.4.6 Trichlorphenol	mg/L	YES	10	10	10	10
Uranium total	mg/L		0.02 c. U	0.02 c. U	0.02 c. U	0.02 c. U
Vanadium	mg/L	NO	0.1 c. V	0.1 c. V	0.1 c. V	0.1 c. V
Zinc	mg/L	NO	0.2 C. Zn	0.2 C. Zn	5.0 C. Zn	5.0 C. Zn
Pesticides						
Aldrin - Dieldrin	µg/L	YES	0.03	0.03	0.03	0.03
Chlordane °	µg/L	YES	0.3	0.3	0.3	0.3
D.D.T °	µg/L	YES	1.0	1.0	1.0	1.0
Endrin °	µg/L	NO				
Endosulfan °	µg/L	NO	70	70	70	70
Heptachlor and heptachloroxyxide °	µg/L	YES	0.1	0.1	0.1	0.1
Lindane (Gama - BMC) °	µg/L	YES	3.0	3.0	3.0	3.0
Methoxychlor	µg/L	NO	30	30	30	30
Polychlorinated Biphenyls	µg/L		2.0			
(PCB´s):	µg/L	YES		0.001	0.001	0.001
Toxaphene °	µg/L	YES	0.01	0.01	0.01	0.01
Demeton	µg/L	NO	0.1	0.1	0.1	0.1
Gution	µg/L	NO	0.01	0.01	0.01	0.01
Malation	µg/L	NO	0.04	0.04	0.04	0.04
Paration °	µg/L	NO				
Carbaryl:			°	0.02	0.02	0.02
Comp. Organophosphates and total carbamates						
2.4.5-TP Herbicida: Chlorophanox	µg/L	YES	10.0	10.0	10.0	10.0
2.4.5-T	µg/L	YES	2.0	2.0	2.0	2.0
RADIATION						
Radiation alfa global	Bq/L	YES	0.10	0.10	0.10	0.10
Radiation Beta global	Bq/L	YES	1.00	1.00	1.00	1.00

Note. Retrieved from Regulation on Water Pollution, 1995, p.263-266

NB-512 Quality of drinking water for human consumption - Requirements

Table D -2 NB-512 Quality of drinking water for human consumption - Requirements

Characteristics		Maximum value	Observations
Hardness		500.0 (mg/L) $CaCO_3$	
pH(1)		9.0	**Limit under 6,5**
Inorganic compounds:			
Aluminium	Al	0.1 (mg/L) (*)	**Higher value has an effect on health**
Arsenic	As	0.01 (mg/L) (*)	**Higher value has an effect on health**
Ammonium	NH_4^+	0.5 (mg/L) (**)	**Higher value influences acceptability, odour and taste**
Antimony	Sb	0.005 (mg/L) (*)	**Higher value has an effect on health**
Barium	Ba	0.7 (mg/L) (*)	**Higher value has an effect on health**
Boron	B	0.3 (mg/L) (**)	**Higher value has an effect on health**
Cadmium	Cd	0.005 (mg/L) (*)	**Higher value has an effect on health**
Calcium	Ca	200.0 (mg/L) (*)	**Higher value has an effect on health**
Cyanide	CN^-	0.07 (mg/L) (*)	**Higher value has an effect on health**
Chlorides	Cl^-	250.0 (mg/L) (*)	**Higher value results in corrosion reflected in taste acceptability.**
Copper	Cu	1.0 (mg/L) (**)	**Higher value influences taste acceptability.**
Chromium total	Cr	0.05 (mg/L) (*)	**Higher value has an effect on health**
Fluorides	F-	1.5 (mg/L) (**)	**Climate change effects should be taken into consideration**
Iron total	Fe	0.3 (mg/L) (**)	**Higher value influences taste acceptability.**
Magnesium	Mg	150.0 (mg/L) (*)	**Higher value has an effect on health**
Manganese	Mn	0.1 (mg/L) (**)	**Higher value influences taste acceptability.**
Mercury	Hg	0.001 (mg/L) (*)	**Higher value has an effect on health**
Nickel	Ni	0.05 (mg/L) (*)	**Higher value has an effect on health**
Nitrites (2)	NO_2^-	0.1 (mg/L) (*)	**Higher value has an effect on health**
Nitrates (2)	NO_3^-	45.0 (mg/L) (*)	**Higher value has an effect on health**
Lead	Pb	0.01 (mg/L) (*)	**Higher value has an effect on health**
Selenium	Se	0.01 (mg/L) (*)	**Higher value has an effect on health**
Sodium	Na	200.0 (mg/L) (**)	**Higher value has an effect on health**

Sulphates	SO_4^{-}	400.0 (mg/L) (**)	
Zinc	Zn	5.0 (mg/L) (**)	
Organic compounds:			
Acrylamide (3)		0.5 µg/L	**Higher value has an effect on health**
Benzene		2.0 µg/L (***)	**Higher value has an effect on health**
Chloroform		100.0 µg/L	**Higher value has an effect on health**
Vinyl chloride		2.0 µg/L	**Higher value has an effect on health**
Epiclorohidrina (3)		0.4 µg/L	**Higher value has an effect on health**
Ethylbenzene		300.0 µg/L	**Higher value has an effect on health**
Phenol		2.0 µg/L	**Higher value has an effect on health**
THM (Total trihalomethanes)		100.0 µg/L	**Higher value has an effect on health**
TPH (Total hydrocarbons)		10.0 µg/L	**Higher value has an effect on health**
Toluene		700.0 µg/L	**Higher value has an effect on health**
Xylene		500 µg/L (***)	**Higher value has an effect on health**

(*) Potential health effects from exposure exceeding the maximum acceptable value (see PAHO / WHO guidelines).

(**) Higher values may influence appearance, taste, odour or damage to other water uses (see OPS / MS guidelines).

(***) The inclusion of these parameters is consistent with WHO-95 guidelines, figures obtained by rounding, assigning 10% of the tolerable daily intake.

Note. Retrieved from NB-512 Quality of drinking water for human consumption - Requirements, IBNORCA, 2010, p.13-14

Appendix E Regularization Form for SARH

ESTADO PLURINACIONAL DE BOLIVIA

AUTORIDAD DE FISCALIZACIÓN Y CONTROL SOCIAL
DE AGUA POTABLE Y SANEAMIENTO BÁSICO

MINISTERIO DE MEDIO AMBIENTE Y AGUA

AAPS
Autoridad de Fiscalización y Control Social de Agua Potable y Saneamiento Básico

REGULARIZATION FORM OF SARH

Date: ☐

1. NATURAL / LEGAL PERSONAL INFORMATION

Natural person ☐
Legal person ☐
Public ☐ Private ☐

Name or Social reason ☐
Legal Representative ☐
License Number of Operation ☐
Nº Registry FUNDEMPRESA ☐
Nº of Environmental License ☐

1.1 Central Office Location

Department ☐ Region ☐ Municipality ☐
Address ☐
Phone(s) ☐ e-mail ☐ Fax ☐

2. SELF-SUPPLY SYSTEM DATA

2.1 Location of the self-supply system

Department ☐ Region ☐ Municipality ☐
Address ☐
Coordinates UTM WGS 84
X: ☐ Y: ☐ Z: ☐
Use Area ☐ Within Area ☐ Outside area ☐

2.2 Types of water sources used by the self-sufficiency system:

Self-supply system for water resources ACTIVE ☐ INACTIVE ☐

a. Groundwater Source (Utilized by wells): ☐

b. Surface Source: ☐ (Specify)

River ☐ Springs ☐ Lake ☐ Lagoon ☐ Others

ESTADO PLURINACIONAL DE BOLIVIA

AUTORIDAD DE FISCALIZACIÓN Y CONTROL SOCIAL
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MINISTERIO DE MEDIO AMBIENTE Y AGUA

AAPS
Autoridad de Fiscalización y Control Social de Agua Potable y Saneamiento Básico

2.3 Data of the system of supply of utilization of an groundwater source. (If you chose option "a" continue filling, otherwise skip to point 2.4)

Drilling Method:
Mechanical ☐ Manual ☐

Name / Identification of SARH	☐	
Start of operation	☐	
Depth of casing	☐	[m]
Diameter of the tubing	☐	[plg]
Type of Cover (Brick, concrete, etc.)	☐	
Material of the pipe of the tubing (PVC, steel, etc.)	☐	
Extraction pipe diameter	☐	[plg]
Initial static level	☐	[m]
Dynamic level	☐	[m]
Pump Depth	☐	[m]
Power of the Pump	☐	[HP]
Energy consumption	☐	[Kw/month]
Pumping Rate	☐	[m^3/month]

2.4 Data of the Superficial Water Supply System. (Fill out only if not filled in point 2.3)

Flow of superficial outcrop ☐ [m^3/h]
Flow of exploitation ☐ [m^3/h]
Ecological flow ☐ [m^3/h]

Observations: ☐

Capture method: ☐

Is there a use of this water source by other users?

Yes ☐ No ☐

If the water resource is used by other users, specify the type of use:

Drinking supply ☐
Agriculture ☐
Livestock ☐
Other (Specify)

Observations: ☐

Av. Mariscal Santa Cruz No. 1392, Edif. Cámara de Comercio, Pisos 16,5 y 4
Teléfono Piloto: (591 -2) 2310801 / Fax: 2310554 / Casilla: 4245
La Paz -Bolivia

3. USE OF WATER RESOURCES

Is there a meter at the source of the water resource?
Yes ☒ No ☐

Use of the water resource for:

Industrial use ☐
Commercial use ☒
Social / Public Use ☐
Domestic use ☐
Others

Specifically describe the use of water resources from the Supply System.

4. VALIDATION OF EFFLUENT DISCHARGES

4.1 Do you make residual water discharges?
Yes ☒ No ☐

If I answer in the affirmative, point 4.1 proceed with the following question and if the answer was in the negative

4.2. Do you make any economic compensation for downloads?

No ☐

Si ☒ Amount: [Bs/month]

Who does the compensation:

4.3 Where do you do your final wastewater discharges?

Sewerage system ☒ Natural receptor body ☐ Others

4.4Do you pre-treat / recycle your wastewater?

Yes ☐ No ☒

Description of the treatment or why it is not performed:

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MINISTERIO DE MEDIO AMBIENTE Y AGUA
AAPS Autoridad de Fiscalización y Control Social de Agua Potable y Saneamiento Básico

5. IMAGE OF THE WATER RESOURCES SUPPLY SYSTEM

6. CONFORMITY OF TECHNICAL INSPECTION

Inspector's Name	Entity	Firm
Inspector's Name	**Entity**	**Firm**
Inspector's Name	**Entity**	**Firm**
Company Representative	**Entity**	**Firm**

NOTE:
* All information filled in this Form is considered an Affidavit.

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